

THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

A REPORT ON
CACAO RESEARCH

1955 - 1956

ST. AUGUSTINE, TRINIDAD, B.W.I.

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1955-1956



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ST. AUGUSTINE, TRINIDAD, B.W.I.

THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

Incorporated by Royal Charter in 1926

G. A. C. HERKLOTS Principal and Director of Research.

Staff

of the

REGIONAL RESEARCH CENTRE

engaged on cacao research

F. W. COPE	...	...	...	...	Senior Plant Breeder.
B. G. D. BARTLEY	...	...	...	...	Plant Breeder.
D. B. MURRAY	...	...	...	...	Senior Plant Physiologist.
R. NICHOLS	...	...	...	...	Plant Physiologist.
G. HAVORD	...	...	...	...	Senior Soil Chemist.
G. K. MALIPHANT	...	...	...	...	Soil Chemist.
K. W. DE WITT	...	...	...	...	Biochemist (Resigned 31.1.56).
L. A. GRIFFITHS	...	...	...	...	Biochemist (Appointed 25.9.56).
P. C. HOLLIDAY	...	...	...	...	Mycologist (Resigned 22.8.55).
R. G. FENNAH	...	...	...	...	Senior Entomologist.
R. ROSS	...	...	...	...	Manager, River Estate.
V. E. WHITE	...	...	...	...	Assistant Manager, River Estate.

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Introduction

SINCE the last report for 1954 was sent to the press prior to its issue in September, 1955, there has been some reorganisation of research effort at The Imperial College of Tropical Agriculture, Trinidad. A Regional Research Centre came into being on 1st September, 1955, and concurrently the three research schemes for banana, cocoa and soils were wound up on 31st August. The Centre does not confine its activities to these three fields though their interests predominate. It has been created primarily to serve some of the long-term needs of the West Indies. With the absorption of the former staff of the Cocoa Research Scheme within the staff of the Centre there is no lessening of research effort on cacao and, moreover, on this crop the research is not confined to Caribbean problems but, as far as local circumstances allow, is world-wide in its range. It is not overlooked that the cost of the research on cacao in Trinidad continues to be met half by the British taxpayer and half by the Cocoa, Chocolate and Confectionery Alliance. A five-year research programme for the Regional Research Centre was submitted to all interested parties, including the Alliance, and the final form was approved and came into effect on 1st September, 1956. Such a five-year programme can only give the broad lines to be followed for precise emphasis must depend on what is discovered during the course of the research. Reference to the section on cacao in that programme and to the papers which follow in this report will show that an effort has been made to solve some of the problems.

With reference to the general strategic plan, two main principles have been adopted. The first is that there is only one problem—the study of the cacao tree in its environment with a view to the increase in yield of good quality beans. The pursuit of this objective means that the work of geneticist and plant breeder, of plant physiologist and biochemist, of entomologist and plant pathologist and of the soils research workers must be integrated towards the common objective. The second principle follows that to achieve this end the research staff must work together as a team. Boundaries between one discipline and another disappear and the possibility of watertight compartments of thought vanish when there is a team approach to a problem. Readers of this report, which covers two years' effort, will be able to decide whether the two guiding principles have in fact been followed.

The paper by B. G. D. Bartley and F. W. Cope on the behaviour of seedling progenies of the breeding programme may well prove to be one of the most important papers of recent years from the research team. With characteristic caution they are careful not to make sweeping statements but even at their modest valuation something of great promise has been achieved. Three types of progenies are described (1) inbreds derived from ICS 1 and ICS 45

selfed; (2) crosses between ICS clones from types within the Trinidad complex and from selections of Nicaraguan Criollo ancestry; and (3) crosses between selected ICS clones and two Witches' broom resistant Upper Amazon clones.

On the negative side there is the fact that the yields both from these inbreds and from crosses of clones with Criollo parentage are low. With the exception of the cross ICS 1 $\times$ ICS 6, none of the seedling progenies of crosses between the selected clones gave yields as great as from rooted cuttings of ICS 1 one year younger than the seedling trees. Also on the negative side: seedling progenies from all possible crosses between the three clones ICS 1, ICS 6 and ICS 8 gave lower yields than did trees grown from rooted cuttings of these three clones.

On the positive side are the results of the crosses between three selected ICS clones and two Upper Amazon clones highly resistant to Witches' broom disease which were introduced by Pound in 1937. All the seedlings from these crosses show remarkable precocity, bearing commencing within two years from planting. Yields from trees three and four years old are very much higher than have been obtained from other cacao types at a similar age. In addition, no vegetative infection with Witches' broom has been observed in the progeny of one of the two Upper Amazon clones (SCA 6) crossed with the three ICS clones; there has been a little pod loss from the disease representing less than 1 per cent. of the yield. Quite apart from the precocity of the seedlings, their phenomenal yields and their very high degree of resistance to Witches' broom there is another very significant result of this breeding work. Since these Upper Amazon clones are self-incompatible the production of hybrid seed in isolation is relatively easy; this in fact means that the production of "clonal seed", or more precisely hybrid seed of known potentiality and parentage, is now a practical proposition. The authors point out that the beans are smaller than those of ICS clones and that their flavour has not yet been assessed but, it must be emphasised, this line of breeding is still in its infancy.

In Trinidad the difference in annual yield between any one cacao tree and its neighbour is frequently relatively large. Substantial differences have been found even between trees of the same ICS clone growing under an equal amount of light, and it is evident that they can occur independently of genetic constitution and of variation in light intensity. R. G. Fennah has sampled yield records of individual trees, taken over a bearing period of twelve years, in Cheesman Field, where ICS clones 1 to 100 are grown in five-fold replicate. His analysis of the data shows that any pronounced fluctuation in rainfall is reflected in the weight of the current or of the following crop, but that both the timing and the direction of the response varies from picket to picket. As the rainfall

was distributed uniformly over the small area sampled, the differences between the patterns formed by the records of successive annual yields cannot be explained as reflecting local differences in rainfall, nor, in view of the correlation with rainfall, can they be attributed simply to local differences in the character of the soil. Such differences, however, can be accounted for by assuming that they result from the effects on tree growth of the root environment created by the interaction between seasonally variable rainfall and different patches of a heterogeneous soil. At each picket there are times when the proportion of soil moisture and of soil air is favourable to growth, and there are other times when it is not. The duration of these periods may vary between pickets, and if the unfavourable period is protracted growth and yield are reduced. It follows that if a planter could control the water supply to his trees, and had a means of judging how to exercise his control in the way most appropriate for each picket, or group of pickets, he would be in a position greatly to increase the yields.

D. B. Murray's paper on deficiency levels of major nutrients in cacao leaves serves to emphasise that when a plant is grown in a culture medium in which there is gross deficiency of a particular element then, not only is the leaf content of that element low as would be expected, but also the leaf content of other elements is affected either positively or negatively. To take but one example: if the soil is deficient in nitrogen the plant accumulates much more potassium in its leaves than it would if the nitrogen supply was adequate. Murray further analyses his results in terms of nutrient ratios and illustrates in table II how with reference to nitrogen deficiency, for example, not only are the ratios of N/P_2O_5 and N/K_2O markedly reduced but K_2O/P_2O_5 is reduced whilst K_2O/CaO is increased. He emphasises that the nutrient status of a leaf is affected by its age and by the light intensity at which it is growing and that these and other factors materially affect the value of leaf analyses for determining the fertiliser requirements of the tree.

The cacao root has been neglected. Without its active growth there cannot be adequate intake of water and of nutrients. T. A. Jones, G. Havord and G. K. Maliphant have investigated the nutrient uptake by excised roots and have evolved a micro-technique. Should excised roots behave similarly to roots attached to a living tree then a new method of assessing nutrient requirements of trees can be established. The experiments show that white excised roots do function similarly to white roots attached to the tree. Considerable refinement of technique is necessary before this new technique can be generally acceptable as a method for determining the nutritional status of the living tree but the results already obtained are sufficiently consistent to justify continued investigation. The technique should be applicable to any root system and it is hoped that research workers on other crops will consider its use.

In the report for 1945-51 Maskell, Evans and Murray described the symptoms of gross nutritional deficiencies in cacao trees and Evans and Murray prepared a series of coloured plates illustrating deficiencies in leaves respectively of nitrogen, potassium, phosphorus, sulphur, magnesium, calcium, iron, manganese, zinc, copper and boron and toxicities respectively caused by excess chloride, metals and boron. G. Havord in his paper in this report gives further evidence on the manifestation in leaves of defi-

ciencies of calcium and magnesium and illustrates his observations with a plate prepared from colour transparencies.

As has been frequently emphasised in papers in this series of reports, the requirement of the cacao tree for nutrients which may be supplied by fertilisers is a subject that has been given much study. The object is of course firstly to determine easily and accurately what is required and secondly to determine whether the fertilisers applied make good the deficiencies. The article by T. A. Jones, G. K. Maliphant and G. Havord should be read carefully. In it the present knowledge of the behaviour of the cacao tree with respect to shade and fertilisers and physical status of the soil is summarised and correlated with the response of the tree in terms of root and leaf flushes. Based on this accumulated knowledge the authors have evolved a logging procedure in which certain measurements are made systematically and at frequent intervals over a long period of time. These involve studies of soil moisture, soil nutrients, leaf constituents, bark constituents, growth data and root constituents; meteorological observations are also being kept. The object of this extensive programme is that the behaviour of the tree in relation to external factors should be the better understood so that the right treatment may be given, after quick diagnosis, to achieve increased yields. The cacao tree is capable of high yields; trees planted in 1949 given the best known treatments have, in the past two years, yielded over 1,400 lb. of dry cacao per acre per year.

Anyone who has ever seen a cacao tree must have been impressed firstly by the very large numbers of flowers borne on the trunk and main branches of the tree and secondly by the large numbers of dried-up small pods, apparently diseased, as compared with the smaller numbers of healthy pods growing to maturity. This failure of pods to grow and their subsequent shrivelling is called cherelle wilt; it is not caused by a disease and must have some physiological significance. There are several possible explanations all difficult to test experimentally and to prove right or wrong. It is a fascinating hypothesis that this physiological wilt is due to a divergence of the food supply from the mature leaves to the successive flushes of young foliage. If only flushing could be prevented whilst the young pods are developing and the organic food manufactured in the leaves could be directed into the pods then yield might be multiplied several-fold! R. Nichols has begun a study of this very difficult and involved problem on the hypothesis that cherelle wilt may be a physiological fruit-thinning mechanism, analogous to fruit drop of apple trees; he has studied the growth substances of cacao and submits a preliminary report.

Two growth substances, which he calls cacao auxin I and cacao auxin II, appear to be involved in the development of the pods. Auxin I, an acid growth accelerator, accumulates in the ovules at a time when physiological wilting is not observed under field conditions. Auxin II, a neutral growth accelerator, follows a similar developmental pattern to auxin I and no doubt both substances are involved in development and maturation of the pods. Auxin I is also found in seedlings and expanding flushes, but it disappears as the leaves mature. An acidic growth inhibitor which has been found in all the tissues which have been examined has not had a physiological function ascribed to it. Nichols suggests that it may be necessary to invoke a hypothesis involving a growth-inhibitory

substance to explain all the experimentally observed facts concerning cherelle wilt.

D. B. Murray and C. J. R. Bridge have investigated and compared the different methods employed to root clonal cuttings of cacao and to harden the rooted cuttings preparatory to planting out in the field. They show that there is little to choose between the seven methods, provided that they are operated efficiently, each yielding between 70 and 80 per cent. of plants. They also compare the costs of the four methods employed on a large scale in Trinidad and show that the cost of operation of the cheapest method is 25 per cent. less than that of the most expensive. All four methods have their merits and the choice must depend on a consideration of local factors.

The problem of what kind of trees to grow as shade trees for cacao has been solved in different ways in different countries. In Trinidad the trees almost universally used are the two Immortelles, *Erythrina glauca*, a native of Venezuela grown in the wet lowlands, and *E. poeppigiana*, a native of Peru grown in the valleys and hills. The beauty of the hillsides in January, February and March is largely due to the prolific flowering of the latter species. Two diseases of the Immortelle are present in Trinidad and are now causing the deaths of trees in several districts. In the hope of finding alternative shade trees for use in Trinidad and elsewhere D. B. Murray, during the past few years, has been experimenting with a number of possible alternatives. His early results are published here as they will be of general interest. It will be recalled that in previous reports Murray described in detail the interactions of shade and fertilisers on the growth and fruiting of cacao.

In the last report Paul Holliday described how he had devised a method for inoculating seeds of cacao with spores of *Marasmius perniciosus*, the fungus causing Witches' broom disease, preparatory to sowing to test the susceptibility or resistance of the ensuing seedlings to the disease. In his paper in this report he presents further results of the CRB clonal trials at River Estate in which he has investigated the resistance of trees of the ICS clones to the disease. His conclusions, which confirm earlier observations, are that (1) wide variations exist in the behaviour of different clones, (2) there is in general a positive correlation between pod and vegetative infection, (3) self-sterile clones tend to form more cushion brooms than self-compatible clones and (4) as far as pod infection

is concerned cuttings and buddings behave similarly. He classifies the clones as resistant, fairly resistant, susceptible and very susceptible and of the forty-six clones examined gives highest marks to ICS 95.

K. W. De Witt has studied the removal of protein from the cotyledons, by hydrolysis and conversion into an insoluble fraction, during the fermentation of cacao beans of the clone ICS 1. He has shown that in well fermented cacao very little protein remains at the end of the process whereas in under-fermented beans the proportion is higher. The amount of protein in the bean could serve as an index of the degree of fermentation.

Conferences

The biennial Cocoa, Chocolate and Confectionery Alliance Conference on Cocoa was held in London from 13th to 15th September, 1955, and was attended by the principal, F. W. Cope, R. G. Fennah, G. Havord and A. L. Jolly. The following papers were presented:

- "Some recent concepts in cocoa research and their relation to a programme of basic research" (R. G. Fennah).
- "Soil conditions for cocoa and their amendment for maximum yield" (G. Havord).
- "The effect of age of tree on cocoa yields" (A. L. Jolly).
- "West Indian clones" (F. W. Cope and A. L. Jolly).
- "The climatic requirements of cocoa with particular reference to shade" (D. B. Murray).
- "Methods of propagation" (D. B. Murray).
- The Inter-American Technical Cacao Committee met at Bahia, Brazil, from 20th to 27th May, 1956. The meeting was attended by B. G. D. Bartley and G. Havord and the following papers were presented:
 - "Methods of breeding and seed production in cacao" (B. G. D. Bartley).
 - "Single plant selection in cacao improvement" (B. G. D. Bartley).
 - "Techniques for determining and remedying nutrient deficiencies in cacao" (G. Havord).
 - "The use of shade for cacao" (D. B. Murray).

Some Early Observations on Seedling Progenies

by

B. G. D. Bartley and F. W. Cope

DURING the two crop seasons ended August, 1955 and 1956, respectively, yield data have become available from the first plantings of hybrid and inbred seedling progenies at River Estate. The majority of progenies have arisen from crosses among some of the Imperial College Selections which were considered to be the most promising at the beginning of the breeding programme. The parents include selections which represent types commonly occurring in the Trinidad complex and selections of Nicaraguan Criollo ancestry descended from material introduced to Trinidad in 1893. Other breeding material includes two Upper Amazon clones—SCA 6 and SCA 12.

The policies of the cacao improvement programme have been outlined by Cope and Bartley (1955). It has been pointed out in this paper and elsewhere that soils and conditions at River Estate are rather atypical of those of the main cacao growing areas in Trinidad. Consequently, results from these experiments may not generally be applicable to normal conditions without advanced testing under such conditions and without further knowledge of the genotype-location interaction. The trees which comprise the plantings reported on in this short paper are still juvenile, and the figures presented may not indicate the potential value of the material when it is fully mature.

All figures are based on the performance of individual trees. Yields are recorded in the field as the weight of wet cacao produced by healthy pods only and have been converted to a dry weight basis by estimating the dry weight as 40% of the wet weight. This conversion factor may be variable, within small limits, from population to population. The numbers of pods infected with Witches' broom disease, caused by *Marasmius perniciosus* Stahel, and by black pod disease, caused by *Phytophthora palmivora* Butl., have been recorded.

Field 8 Progeny Rows

The first seedling progenies were planted in progeny rows without randomisation, at a spacing of 12 ft. $\times$ 12 ft., in December, 1948. The progenies represent four crosses and two inbreds, involving as parents ICS 1, ICS 6 and ICS 44 (Trinitario) and ICS 45 and ICS 60 (Criollo parentage). All parents, except ICS 60, are self-compatible. Cuttings of ICS 1 were interplanted among the progeny rows but only in 1950. Table I gives the yields from the crosses for two years.

No definite comparisons can be made among the crosses owing to the large differences in population size and the possibility of confounding crosses with soil effects. The features of this planting are the low yields recorded for the

inbreds and the inferior performance of crosses with Criollo parentage. The latter group also has a lower proportion of bearing trees. The low yield of the cross ICS 1 $\times$ ICS 45 may be attributed in part to the fact that all trees of this cross are self-incompatible.

TABLE I

Yields (lb. dry cacao/acre) of seedlings and cuttings in Field 8 for 1954-55 and 1955-56

Cross	No. of trees planted	1954-55 (Age 6 yrs.)		1955-56 (Age 7 yrs.)	
		No. trees bearing	Yield-lbs. dry cocoa/acre	No. trees bearing	Yield
ICS 1 $\times$ ICS 6	47	35	634	38	904
ICS 1 $\times$ ICS 44	18	15	392	17	774
ICS 1 $\times$ ICS 45	215	180	383	198	484
ICS 45 $\times$ ICS 60	34	21	432	25	611
ICS 60 $\times$ ICS 45	156	83	567	107	647
ICS 1 selfed	26	7	233	11	376
ICS 45 selfed	64	10	163	28	322
ICS 1 cuttings*	124	120	640	123	861

* Rather more than one year younger than the accompanying seedlings.

Field 19—Seedlings v. Cuttings

This experiment compares cuttings of the clones ICS 1, ICS 6 and ICS 8, and seedling progeny of the three possible crosses among these clones. Planting was done in 1950 with the exception of the cross ICS 6 $\times$ ICS 8 which was planted in 1951. Trees are spaced at 12 ft. $\times$ 12 ft. and are laid out in a randomised block design with four replications, each clone or cross being represented by 100 trees. Data obtained for the 1955-56 crop are given in Table II.

TABLE II

Yield (lb. dry cocoa/acre) and other data for 1955-56 crop from Cuttings vs Seedlings experiment

Clone and Cross	No. of trees bearing	Yield	% pods infected with witches' broom
ICS 1	100	783	4.9
ICS 8	99	752	17.9
ICS 6	91	534	6.3
ICS 1 $\times$ ICS 8	92	517	4.6
ICS 6 $\times$ ICS 8	86	403	6.4
ICS 1 $\times$ ICS 6	74	308	5.4

In general, at this early stage, cuttings of the three clones are definitely superior to the crosses with which they are compared. However, no definite conclusions as to the value of the crosses can be made until a greater range of material of more advanced age is available for study. It appears that ICS 8 is superior to ICS 1 and ICS 6 as a parent.

Trinidad x Scavina hybrids

An attempt was made to combine the desirable agromomic characters of some Imperial College Selections with the high level of resistance to *Marasmius pernicius* possessed by two trees introduced by Pound in 1937 and designated as SCA 6 and SCA 12 (SCA = Scavina). Crosses were made between these clones and ICS 1, ICS 6 and ICS 60 and the progeny were planted in 1951 in a randomised block design at a spacing of 7 ft. x 7 ft.

All seedlings showed a remarkable precocity, with bearing beginning within two years from planting. Yields recorded when the trees were three and four years of age

are given in Table III, figures representing pounds of dry cocoa per acre for all trees. These yields are very much higher than have been obtained from other cacao types at a similar age. Unfortunately, figures for other material planted in this trial are not available for comparison. However, cuttings of ICS 1 planted at 8 ft. x 8 ft. at River Estate have yielded 600 lb./acre when four years old.

So far, no vegetative infection by *M. pernicius* has been recorded on trees with SCA 6 as a parent. Several trees of the three other crosses have been infected, the numbers being 44 trees each (about 26%) for ICS 1 x SCA 12 and ICS 6 x SCA 12, and 56 (about 35%) for ICS 60 x SCA 12. The proportion of infected trees in each cross is expected to increase with time. Although pod losses from this disease have been relatively small, a similar relationship in the nature of resistance of SCA 6 and SCA 12 is seen in the figures for infected pods given in Table III; seedlings of SCA 6 parentage lose less pods from Witches' broom attack than those of SCA 12 parentage.

TABLE III

Yields (lb. dry cocoa/acre) for two seasons, and disease losses for one season, of Trinidad x Scavina hybrids

Cross	1954-55		1955-56			
	Yield	% bearing trees	Yield	% bearing trees	% pod loss due to Witches' broom	Black pod
ICS 1 x SCA 6	840	90	1,283	93	0.94	1.25
ICS 1 x SCA 12	790	83	1,432	89	0.79	1.63
ICS 6 x SCA 6	1,025	94	1,461	89	0.56	0.96
ICS 6 x SCA 12	900	87	1,410	88	1.10	0.95
ICS 60 x SCA 6	660	83	1,086	86	0.47	1.46
ICS 60 x SCA 12	825	81	1,504	90	1.38	2.05

Pod size and bean size of the progeny are intermediate to those of the parents, with perhaps a tendency towards being closer to the size of those produced by the Upper Amazon parent, particularly in trees producing large numbers of pods. Relative pod and bean sizes in terms of the number of pods required to make a pound of dry fermented cocoa and the mean weight of processed beans are presented in Table IV. The values for SCA 12 progeny are consistently higher than those for SCA 6 progeny. These differences are observed in the parents themselves. SCA 12 requires about 13.0 and SCA 6 about 14.5 pods to produce a pound of dry cocoa.

The high level of performance of these hybrids is sufficiently promising to justify advanced testing of these hybrids and of further combinations of this type of material. Since the Scavina parents are self-incompatible, production of hybrid seed in isolation is relatively easy and inexpensive and large-scale plantings for bulk cacao production may be composed of such material providing it is as well adapted to specific conditions as other available planting material. Suitability of these hybrid seedlings

to local conditions may depend on their potential value from the flavour point of view and it proposed to submit samples of cocoa from these crosses for assessment of flavour. Apart from the value of the Trinidad x Scavina hybrids as planting material they provide a very promising source of germplasm for further cacao improvement, particularly for increased yields and resistance to the major fungus diseases in Trinidad.

TABLE IV

Pod values and bean sizes for six Trinidad x Scavina hybrids

Cross	Pod value (pods/lb.)	Mean weight of dry beans (grams)
ICS 1 x SCA 6	9.7	1.08
ICS 1 x SCA 12	9.3	1.12
ICS 6 x SCA 6	10.1	1.14
ICS 6 x SCA 12	9.4	1.18
ICS 60 x SCA 6	11.4	1.10
ICS 60 x SCA 12	10.8	1.23

Reference

- COPE, F. W. and BARTLEY, B. G. D. (1955). Some aspects of the plant improvement programme. *A Rep. on Cacao Res.*, 1954. Imperial College of Tropical Agriculture, Trinidad.

An Analysis of Yield Variation in a Sample of Cacao Trees

by
R. G. Fennah

IN Trinidad the difference in annual yield between any one cacao tree and its neighbour is frequently relatively large, and has been attributed partly to genetic heterogeneity and partly to soil heterogeneity. In the past decade the widespread use of clonal cacao has permitted the fact to emerge that variation in yield even between adjacent trees of the same clone may be of a magnitude comparable with that between seedling trees. This finding has emphasised the importance of the second factor and has raised the possibility of additional factors being involved. In the present paper an attempt is made to analyse the components which make up the yield of a sample of trees, and to determine how they vary in relation to time.

Methods

Yield records were available of individual trees in Cheesman Field, San Juan Estate, from 1944 to 1956, that is from the first year of bearing until the twelfth. The trees in this field comprise the ICS clonal series 1 to 100 in five-fold replicate, planted in numerical sequence. Monthly rainfall records for the same period were available from Santa Maria Estate, situated about a mile from Cheesman Field on the opposite side of a valley.

Two sets of samples were taken. The first was intended to provide a comparison of the yield behaviour of high yielding and low yielding trees, and for this the yield records of five pickets of each of the ICS clones 89, 95 and 1 were taken, the first of these having yielded well in this field, the second satisfactorily and the third poorly. The second sample was taken to provide a comparison of yield variation from tree to tree in a block. For this the records were used of three 3×3 groups of trees, all situated in the 400-500 block at Cheesman Field. This block is in the most fertile part of the field, and the groups were selected on account of their content of high yielding trees. Selection was made in this manner to ensure, as far as possible, that only intrinsically fertile sites were considered. Each tree in Cheesman Field is identified by the number of the clone preceded by the number of the block: the first of the 3×3 groups contained trees 435, 436, 437, 448, 449, 450, 451, 452 and 453, the second and third slightly overlapped and included trees 465, 466, 467, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 492, 493 and 494. The yield and rainfall records are given in the Appendix.

The two elements involved in the yield records—upward trend with age and annual fluctuation—were separated by estimating the trend for each tree by the method of least squares, usually from the seventh to the fourteenth year of

growth (fourth to eleventh of yield), and deducting the appropriate calculated value from the actual yield record for each year. The residual amount, positive or negative, was used as an expression of annual fluctuation.

The monthly rainfall records were totalled to show “annual” and “crop-year” precipitation, the first embracing the calendar year and the second an arbitrary period beginning on 1st May and ending on 30th April of the following year. In addition the fluctuations in “calendar year” and “crop year” totals from year to year were smoothed by tabulating the averages between successive values. The yield trends were compared on a basis of equal time interval, and the yield fluctuations from year to year were compared in turn with each classification of the rainfall data. Subsidiary residual variation was analysed in a similar manner, as described later.

Results

It was found that the yields, in space and time, could be apportioned between four components, considered under (a) to (d).

(a) The yield trends for five pickets of ICS 89, ICS 95 and ICS 1 respectively and for the average of the samples from the 400-500 block are shown in Fig. 1. The yield trend of the highest yielding tree in the field, ICS 89 in the 0-100 block, is plotted separately.

(b) The annual variation in yield of the fifteen trees of ICS 89, 95 and 1 was considered together with that of trees in the 400-500 block. It was found that the pattern of yield variation of any one tree could be assigned to one of five groups: (1) variation correlated positively with rainfall of the same year; (2) variation correlated negatively with rainfall of the same year; (3) variation correlated positively with “smoothed” rainfall of the preceding year; (4) variation correlated negatively with “smoothed” rainfall of the preceding year (or even the preceding but one); (5) variation correlated positively with current annual rainfall below 96 inches and negatively above. The data are given in Figs. 2 to 7. The correlation coefficients of Figs. 2 to 6, and the mean difference between the yields of eight pickets at 96 inches of rainfall and their corresponding yields below and above this amount are statistically significant at various probability levels below $P = 0.05$.

For clarity of presentation only averaged yield values are entered in Fig. 7. The yield patterns of the individual pickets of this group agree closely with one another except for the occurrence of the highest yield at two pickets (492 and 495) at 92 inches of rainfall.

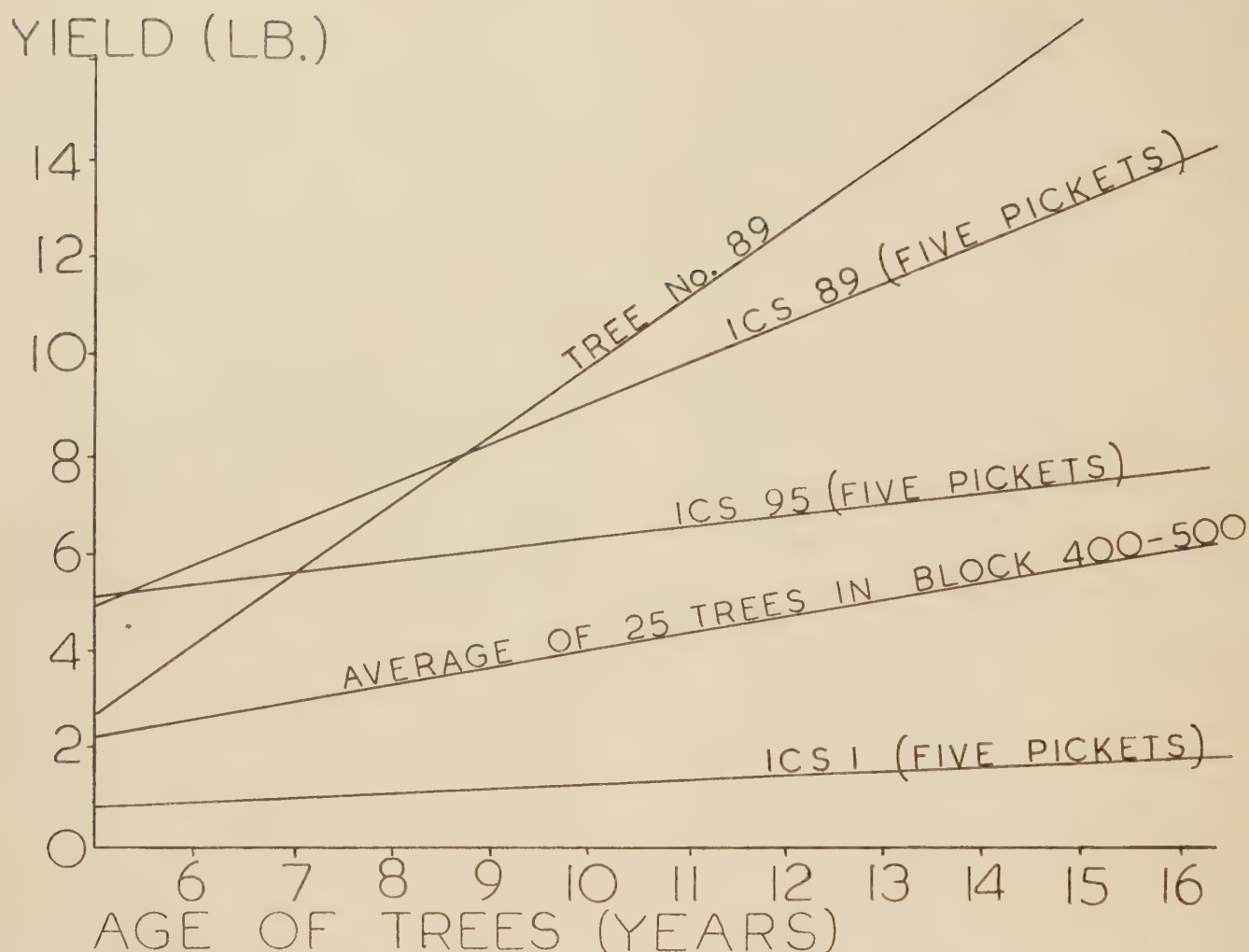


FIGURE I

Yield trend in relation to age of ICS 89, ICS 95, ICS 1, of tree No. 89 and of the average of twenty-five trees in the 400-500 block in Cheesman Field.

The trees comprised in each correlation-group are as follows: Group 1: 1, 101, 201, 301, 436, 437, 450, 476, 479, 480, 483, 496; Group 2: 89, 95, 189, 289, 389, 395, 449, 465, 466, 484, 485, 489; Group 3: 195, 401, 481; Group 4: 435, 451, 452, 453, 477, 480 with 467 negatively correlated with "smoothed" rainfall values of two years previously; Group 5: 295, 448, 478, 482, 492, 493, 494, 495.

(c) Regression lines of yield on rainfall were calculated for each group and the divergences of the actual values from the regression line were tabulated for each correlation-group for each year from the eighth to the thirteenth or fourteenth inclusive. The divergences from this line of the actual values for groups 1 and 3 were averaged for each year to which they respectively applied. Those of groups 2 and 4 were similarly treated. These averages, which represent fluctuation of yield not correlated with annual rainfall, were found to be correlated positively and negatively respectively with rainfall during the preceding dry season (Fig. 10).

(d) The divergences of values recorded in Fig. 10 from their respective regression lines were again tabulated for each correlation-group. This residual variation, in the

"positively correlated" group, proved to be positively correlated with September rainfall during the current crop (Fig. 11). The divergences from the regression line in Fig. 11, after an adjustment described below, were found to be positively correlated with rainfall during July and August (Fig. 12).

The residual variation in the "negatively correlated" group, after a correction for "buffering" had been applied, proved to be negatively correlated with rainfall during December to March inclusive in the same crop year (Fig. 13).

Discussion of results

General features of the case-histories

Notwithstanding their great diversity, the yield histories of the trees sampled agree in a few well-marked features. Firstly came a period, beginning with the fourth year after planting and extending up to the sixth, or more usually the seventh, and occasionally the eighth, when fluctuation from one year to another was violent, if judged by the standard of later years. This exceptional sensitivity is here tentatively interpreted as being associated with

juvenile growth, and the depressions possibly reflect the effect of competition for nutrients from the vegetative growing points. Secondly, a period of relatively "wet" years (eighth to twelfth) was followed by one of relatively dry (thirteenth to fifteenth). Finally, a strong general depression of yield occurred in the fifteenth year of growth, and its uniformity and extent point to an incursive factor other than meteorological. There is little reason to doubt that this is the result of a heavy pruning which took place in July, 1954, immediately before the crop season of 1954-55.

Yield trend with age

As all the clones sampled are known to be capable of giving high yields in appropriate circumstances, and as the sites on which they are situated may be accepted as comparatively fertile, the yield trends approximately reflect the net rate of assimilation of the trees. The steepest upward trend in the present samples is that of ICS 89 in the 0-100 block (Fig. 1). If this is used as a standard of good performance, the yield trend of the averaged samples from the 400-500 block must be considered as unimpressive. Yet the average yield per tree in the samples from this block in 1956 was 5.7 lb., a level which compares very favourably with the three-quarters of a pound per tree estimated as a general average of Trinidad seedling cacao. It is clear that even in an area with considerable natural advantages (as in this block of Cheesman Field), and when only trees of superior type are grown, a considerable loss of potential yield may be sustained every year. In less favoured areas this "hidden" loss is proportionately greater, and its reduction poses the main problem in local cacao agronomy.

The values given by extrapolation of the yield trends to cover the first three or four years of fruiting in some cases bear little resemblance to those of the crop actually picked in these years. The early yields of ICS 89 in the 0-100

block (as, indeed, of all five trees of this clone) fluctuate fairly evenly above and below the trend line, and in view of the consistently good growth of this tree in subsequent years may reasonably be regarded as typifying the performance to be expected of a tree yielding in normal dynamic balance with its vegetative growth. If this is so, the remarkable yield of 14 to 16 lb. of dry cacao which was recorded at each of three pickets of ICS 95 in the fifth year of growth (second year of fruiting), when viewed in the light of subsequent performance, suggests a temporary metabolic derangement rather than a normal entry into the bearing phase (Fennah 1955b, plate 28). The mechanism which evoked such a high yield is unknown, but the fact that two trees of this clone did not behave in the same way suggests that the operative factor was associated with the planting site.

The rate of yield increase with age may be considered as being determined by the interaction of two factors, these being the intrinsic nutrient level of the site and the time, in any one year, for which the tree can make relatively unimpeded growth. Where differences in both factors favour one tree in comparison with another their combined effect may result in a comparatively large difference in yield even if the differences between the respective factors are slight. If the interaction between soil fertility and duration of unimpeded growth consistently favours one of two trees, then, other things being equal, a consistent divergence in yield trend will result.

Yield and rainfall

The fluctuations from year to year in the yield of trees in the samples show considerable diversity, and if consideration is limited to trees sampled in the 400-500 block, the range of patterns from so small an area is remarkable. Nevertheless, all patterns agree in showing that the influence of rainfall is strong. At some pickets, yield increases in years when rainfall is high, whereas at others it decreases;

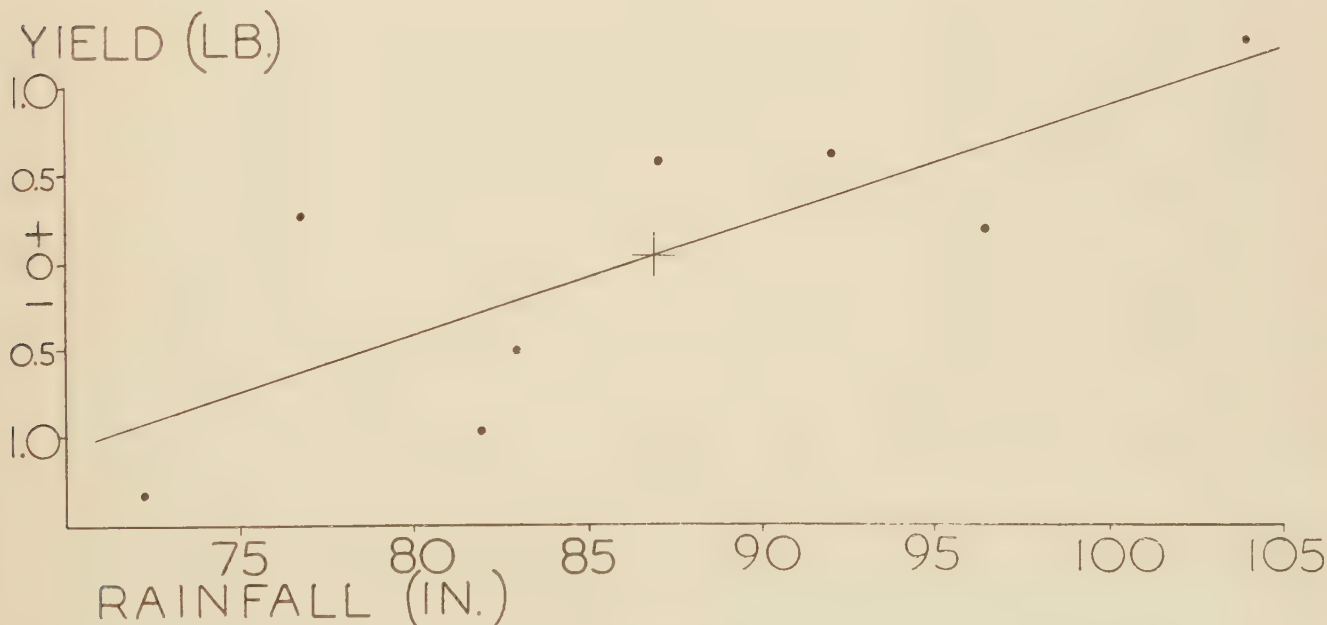


FIGURE 2

Relationship between the average yields of pickets of Group 1 and rainfall of the corresponding year.

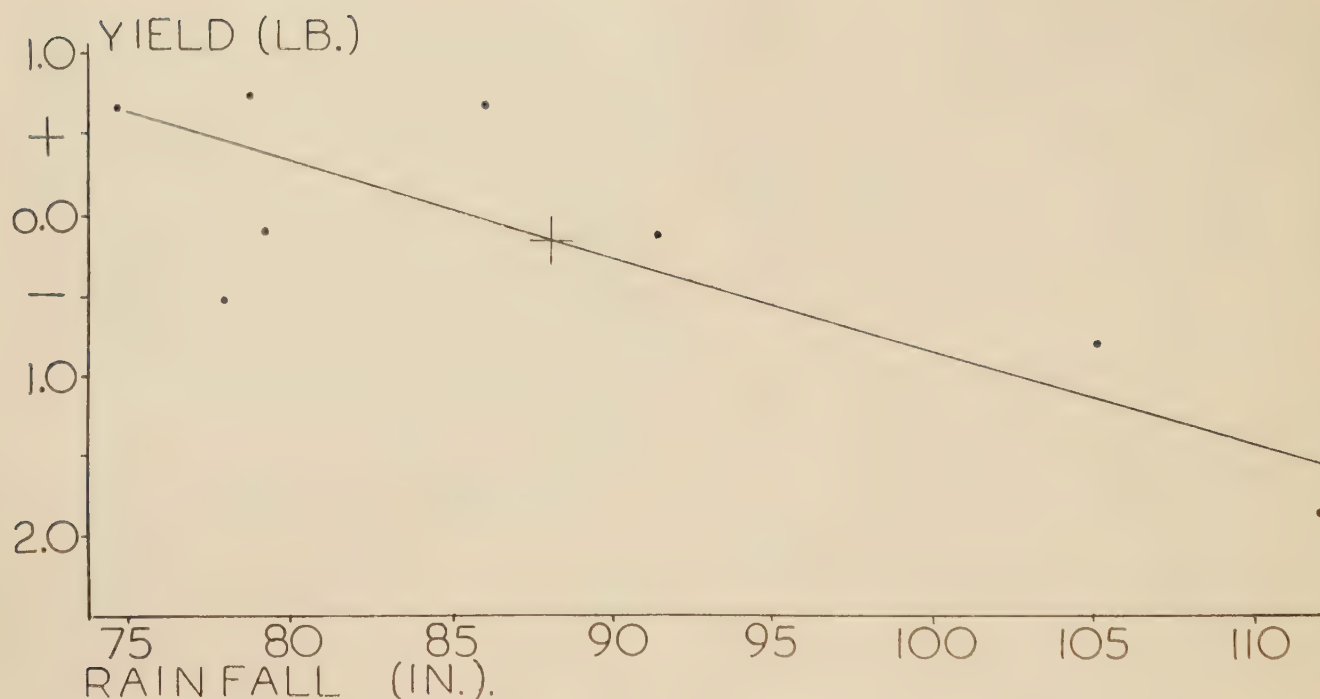


FIGURE 3

Relationship between the average yields of pickets of Group 2 and rainfall of the corresponding year.

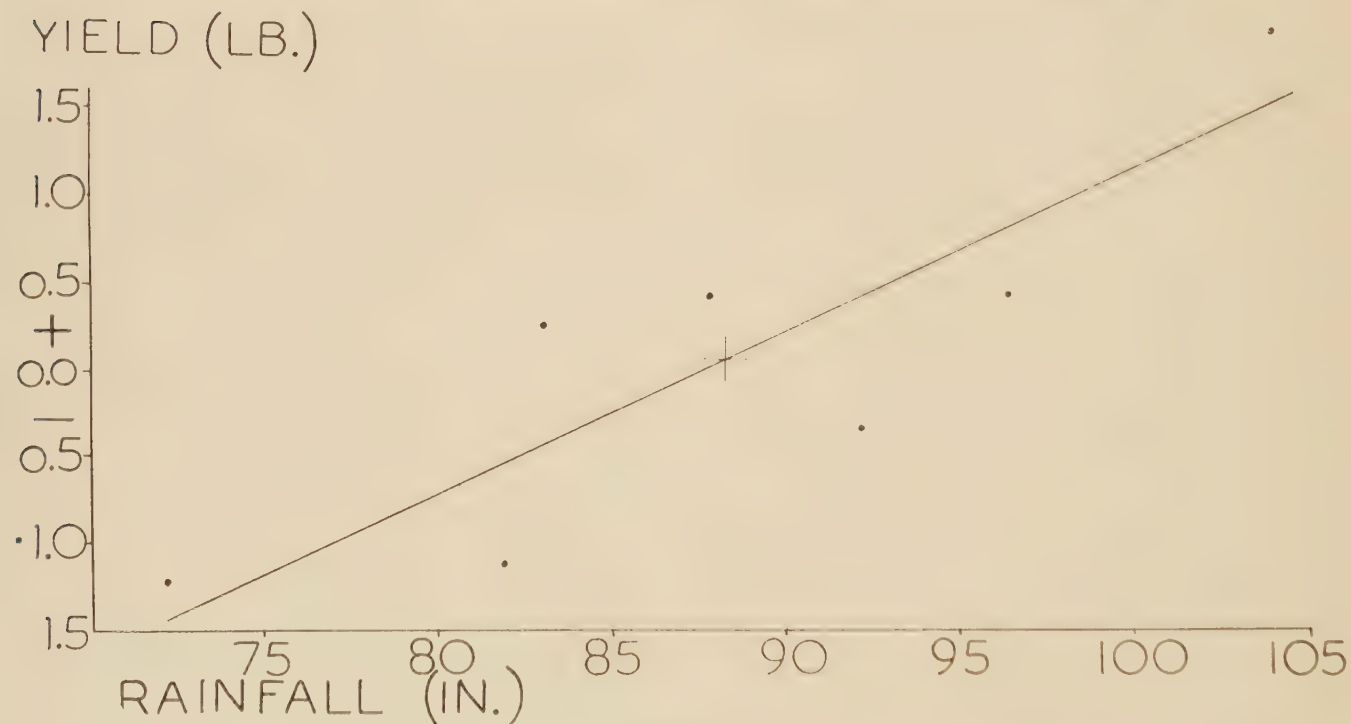


FIGURE 4

Relationship between the average yields of pickets of Group 3 and rainfall of the preceding year.

at others again, the best yields are obtained only when the rainfall total falls within specific limits. As the pickets showing these differences are situated within an area of 160 square yards, and are under the same degree of Immortelle shade, it must be accepted that all have received the same amount of rain at every shower, and that the patterns of fluctuation, in so far as they are correlated

with rainfall, to a large extent reflect the influence of this water when it reaches the zone of soil occupied by the absorptive rootlets.

After the first few years following planting, if the soil is left undisturbed, its structure at any given spot in a field bearing cacao may be regarded as fairly constant from one year to the next, at least over a short period of years.

Where, as in Trinidad, the annual rainfall conforms to a fairly definite pattern of four months of low precipitation followed by an abrupt rise, then an undulating fall extending over eight months, it is likely that at pickets where increase in yield accompanies increase in rainfall the water supply to the roots is deficient for part of the year and adequate for the remainder, and that in a "wet" year the period for which the soil moisture is adequate is longer, and growth is accordingly unimpeded for a longer time than usual. This interpretation agrees with the data for dry-season precipitation (Table I).

TABLE I

Dry season rainfall and yield in the following season at twelve pickets where yield is positively correlated with total annual rainfall

Year	Inches of rainfall January-April	Mean yield per tree (lb.) in following crop after deduction of yield trend with age	
1952	4.96	1.30	
1949	6.41		0.03
1947	8.40	0.75	
1953	9.20		0.36
1948	14.41		0.41 $r = +0.54$
1950	21.36		1.17 $P = 0.01$
1951	30.75		0.11

The yield patterns of ICS 1, and ICS 81 in the 400-500 block and ICS 95 in the 100-200 block, which are positively correlated with rainfall in the *previous* year, may perhaps

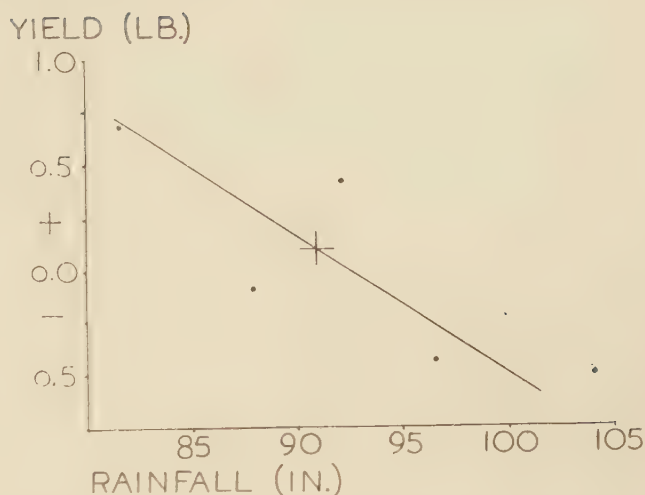


FIGURE 5

Relationship between the average yields of pickets of Group 4 (excluding tree 467) and rainfall of the preceding year.

be explained by assuming the existence of a tendency in these trees to accumulate reserves in one year and to expend them in the next.

At pickets in Cheesman Field where increase in yield accompanies decrease in rainfall, the principal retarding factors are believed to be twofold; firstly, a period of suboptimal soil aeration may occur during a part of the wet season, and secondly, during periods when the soil

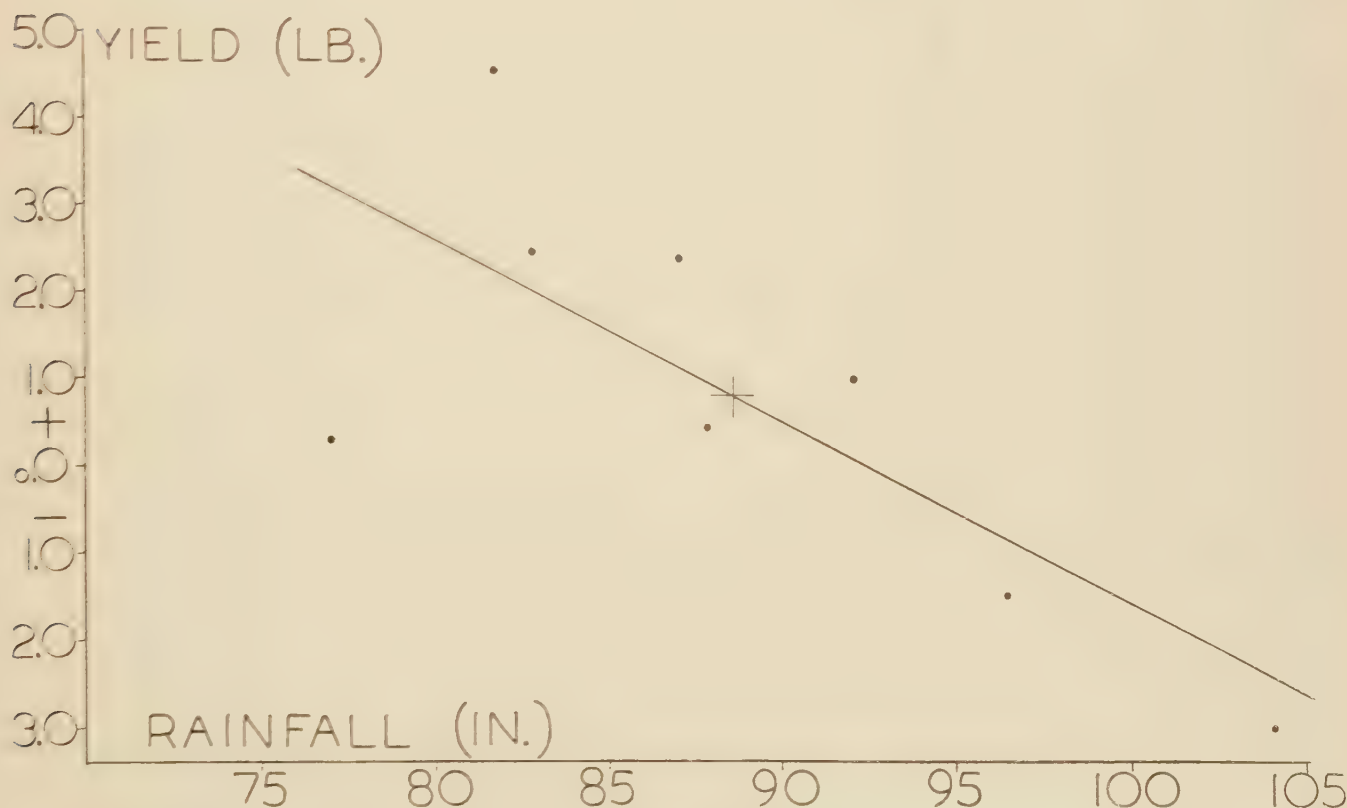


FIGURE 6

Relationship between the yields of tree No. 467 and rainfall of the previous year but one.

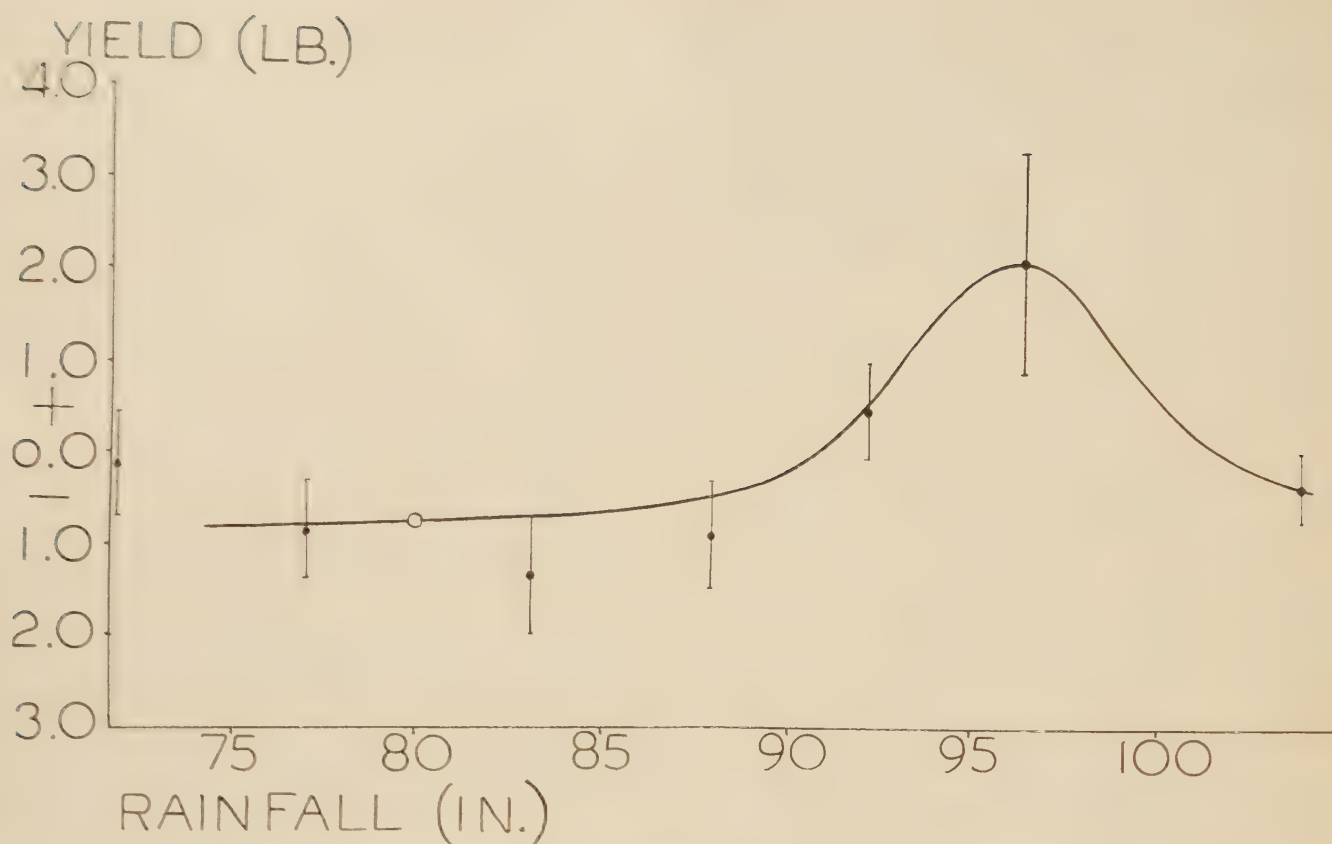


FIGURE 7

Relationship between the average yields of Group 5 and rainfall of the corresponding year. The circle represents the average of the four entries below 90 inches. The vertical lines indicate the standard error of each entry.

moisture level is high, the ratio in which certain nutrient elements are assimilated from the soil may be altered, and particularly the absorption of calcium may be enhanced and that of potassium depressed. It is a matter of observation that "lime-induced chlorosis" occurs on many trees in this field during the later part of the wet season (Fennah 1955a: 19), and disappears in the dry. The beneficial effects of dry weather, in any year in Trinidad, are not likely to be experienced in the main part of the wet season, and it is reasonable to assume that for trees in this correlation-group they result either from the soil drying out more quickly towards the end of the previous wet season, or from delayed onset of the heavy rains, or from both. The first possibility is supported by the data shown in Figs. 10 and 13.

Fruit-setting begins soon after the beginning of the rainy season, approximately in June, and the last pods of the annual cropping cycle ripen in the dry season of the following year. Each pod requires not less than seventy days to reach a stage at which its development to full size is assured, but does not become fully ripe until five months have elapsed (Humphries 1940: 35). Pod counts taken at appropriate intervals permit the crop to be fractionated according to time of development, and such data were available for the present study.

Examination of the percentage of the crop which develops to the "safe" stage between the onset of the rainy season and the beginning of September showed that it did not vary significantly between trees with yields

positively correlated with rainfall and trees with yields negatively so correlated. Its fluctuations from year to year were closely similar in both groups and were positively correlated with rainfall in the dry season immediately preceding, as long as the total precipitation did not exceed 25 inches between January and April, inclusive ($r = +0.65$, $P = 0.01$). This behaviour may reflect the influence of dry seasonal weather on the inception of flowering, or on the hydration of the tissues at the time of pod-setting.

The percentage of the crop developing after December was compared with rainfall over a period of years. Here again trees of opposite yield-correlation with rainfall behaved with remarkable uniformity as regards fluctuation in relative size of the late crop. The rainfall values used were the "smoothed" values of rainfall for the calendar year. The percentages which the late crop formed of the total crop in the sixth to the ninth years of growth were very much higher than those from the tenth year and onwards. These "early" percentages were arbitrarily corrected by dividing the values for the first four years by three. The set of percentages which resulted proved to be almost perfectly negatively correlated with the smoothed rainfall values, as shown in Table II.

This change agrees with that recorded for the early part of the crop in showing an advance of the time of successful pod-bearing in wet years.

The high percentage which the late crop formed of the total in the early years of fruiting may be accounted for

TABLE II
Percentage of total crop developing after December in
relation to "smoothed" annual rainfall

Year of growth	Late crop as percentage of total	Arbitrarily corrected yields	Rainfall (inches)
6	47.0	15.7	87.1
7	54.2	18.1	82.2
8	61.3	20.4	83.0
9	48.9	16.3	92.2
10	15.3	15.3	96.6
11	13.2	13.2	104.1
12	18.1	18.1	87.8
13	22.8	22.8	72.3
14	21.2	21.2	76.9

by assuming that in the early part of the wet season the vegetative growing points of the young trees competed more intensively with the fertilised flowers and young pods for nutrients, and that it was not until the months of most active vegetative growth were past that fruit were set and carried to ripening. The shift from late to "early" and "middle" cropping is perhaps to be assumed as having occurred when the trees attained a certain stage of physiological maturity. If such is the case, however, it is a matter for surprise that the transition should have occurred with the abruptness shown in the data.

The final class of relationship of yield with annual rainfall found in the samples is that in which yield is highest when total annual rainfall amounts to approximately 96 inches (Group 5). The trees of this group differ considerably in their average yield, and it is evident that fertility of the site must play an important part in determining the amount of growth which can be made when water relations are satisfactory. It might be expected that a water requirement of such apparent nicety as that of this group would not be met, under prevailing conditions, for more than a short time in each year, but the high yields of the best trees in this group (Nos. 295, 448 and 495) indicate that at some pickets at least the period is sufficiently long.

The various patterns of yield fluctuation in the samples attributable to the influence of annual rainfall can be represented by appropriate sections of a model which embodies the generalised features of water relationships, as shown in Fig. 8.

In this scheme the framework for expressing the various relationships is a curved surface which represents the relationship between yield, water deficit and the effects of water excess (c). The base of this model (a) represents a range of annual rainfall values along the ordinate axis: the terms "high" and "low" express divergence from an optimum position at the middle. The numerical value, in inches of rainfall, which corresponds to this optimum varies with the planting site, and probably also with the

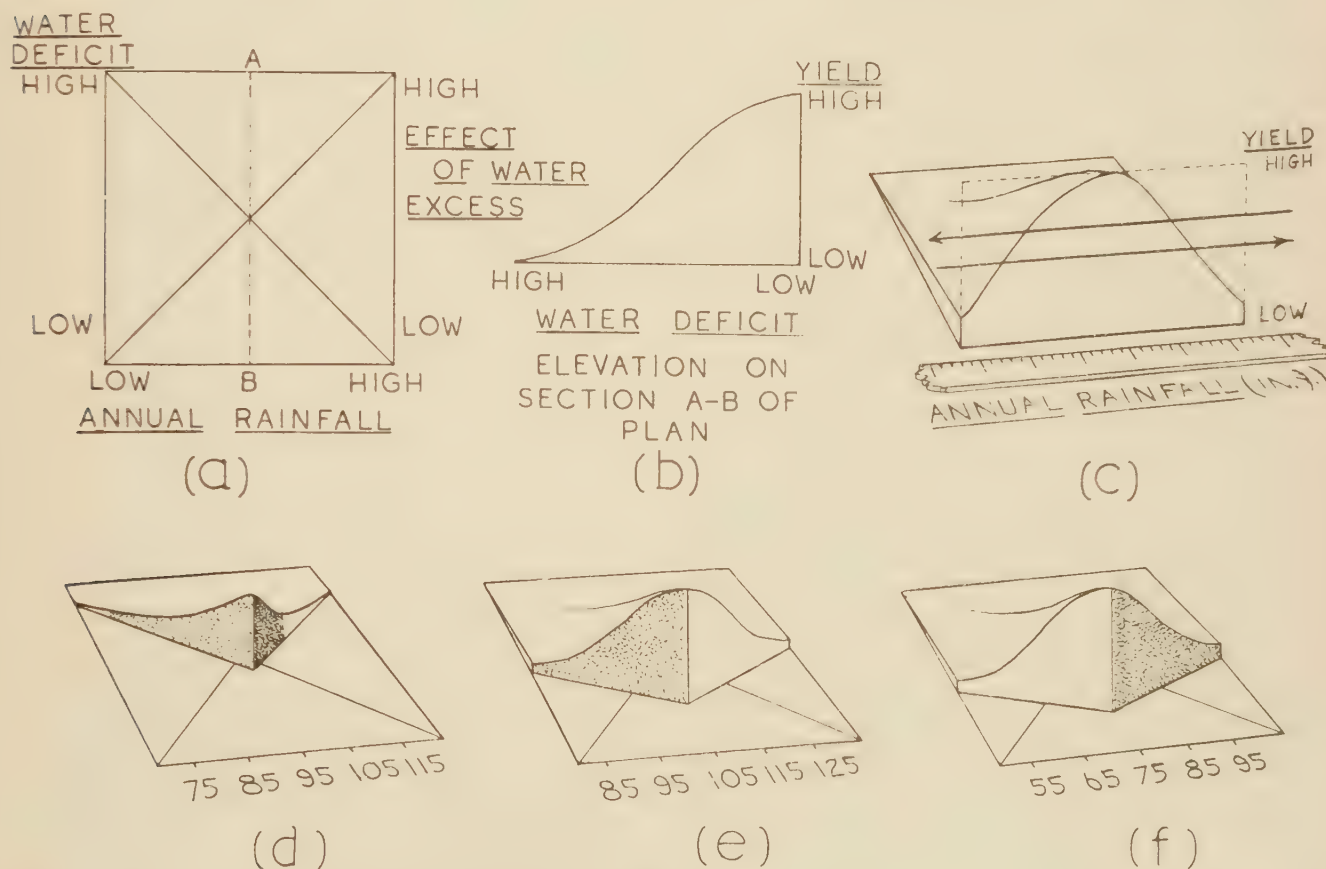


FIGURE 8

Schematic representation of the general relationship between the effects of water deficiency and water excess on yield (a, b, c) and the approximate yield curves in relation to rainfall of trees (d) positively and negatively (e) positively and (f) negatively correlated with rainfall. The stippled areas represent approximately the data shown in Figs. 7, 2 and 3 respectively.

PICKET • SHADE TREE ○ SLOPE ↗

LIMESTONE OUTCROP ■

37	48	53
+	±	-
36	49	52
+	-	-
35	50	51
-	+	-



76	85	92	
-	-	±	
77	84	93	
-	-	±	
67	78	83	94
-	±	+	±
66	79	82	95
-	+	±	±
65	80	81	96
-	+	+	+

FIGURE 9

Plan of pickets sampled in the 400-500 block of Cheesman Field, showing the class of yield correlation with rainfall and topographical features of the site. Symbols: yield positively correlated with rainfall (+), negatively (-) and positively when rainfall is below 96 inches and negatively when it is above (±). The broken line traversing the plans segregates pickets of negative sign.

rainfall distribution, where this differs from that found in Trinidad. To allow for this, the whole model is to be regarded as movable laterally along a fixed scale of annual rainfall values, as indicated by arrows in (c). The abscissae of the base represent on one side degrees of water deficit in the tree, with the diagonal line defining the broad relationship of water deficiency to rainfall, and on the opposite side the relationship between the effects of water excess on the tree and rainfall. The vertical axis represents a range of yield values, expressed in relative terms. Approximate numerical values can be inserted for each example taken from Cheesman Field, but in a general scheme the model must be regarded as free to move vertically along a suitable scale of yield.

The response in yield under different amounts of annual rainfall given by trees of positive-and-negative yield correlation can be shown by marking a locus, or arc of movement, on the base of the model, taking the triangle based on the ordinate axis of rainfall and bounded apically by the intersection of the diagonals as the zone of optimum growth and yield. This locus can be produced vertically to intersect the upper surface of the model and thus give an outline in profile which represents all the variations in yield which are possible in this group under any degree of annual rainfall. Similarly, a locus can be traced for trees with yields positively or negatively correlated with rainfall; in this case, however, it can only be surmised how far the highest yield increase noted in the samples is to be entered from the peak of their respective curves.

At any one site, movement of the point indicating yield value along the upper surface of the model will take place with corresponding (or antagonistic) movement of the point along the ordinate indicating the annual rainfall. Where the yield point refers to trees with yields correlated with rainfall in the current year its movement will synchronise with that of the "rainfall" point: where it refers to trees with yields correlated with rainfall in the previous year, movement of the "yield" point will follow that of the "rainfall" point after an interval of one move.

The contrast in cropping behaviour of the trees sampled in the 400-500 block was sufficiently large to suggest the existence of gross differences between the sites on which they grew. Each tree was accorded a symbol appropriate

to the type of correlation existing between its yield and the recorded rainfall, and these were entered on a plan of the field to give the distribution shown in Fig. 9.

These sites were examined in the middle of the wet season and it was found that trees with a negative sign were situated on a comparatively deep (more than 2 ft.) close-textured silty clay, very wet, while trees with a plus or plus and minus sign were situated on a soil which at a depth of a few inches bore particles of decomposing rock and was in part of "gritty" texture. Moreover, the latter trees were closely associated with outcrops of limestone. The broad structural features of the sites are thus reasonably in conformity with the indications given by the yield data.

Before leaving this topic it is worth mentioning a few features of the site on which grows ICS 89, the "standard" tree in Cheesman Field. This picket is on the shoulder of a low minor ridge at the foot of a high escarpment. The soil is dark and compaction is slight. The most noteworthy feature is the presence of a large Immortelle immediately adjacent to the picket. This provides light shade on two sides of the tree and rather heavy shade on the remaining two. It would seem inevitable that the soil volume exploited by the roots of the cacao-tree is equally open to exploitation by those of the Immortelle, yet the negative correlation of the yield at this picket with current rainfall and the steep yield trend suggest that competition between these trees for water in the dry season, and for soil nutrients at any time, is of negligible importance.

The yield records were compared not only with rainfall, but also with hours of sunshine per annum, as measured at the Imperial College of Tropical Agriculture, seventeen miles from Cheesman Field. The values for annual hours of sunshine, when smoothed, were found to be highly negatively correlated with the "smoothed" rainfall values of Cheesman Field. Yield-patterns which are negatively correlated with rainfall are positively correlated with hours of sunshine and *vice versa*. Now it is conceivable, on parts of Cheesman Field, that excessive insolation in its net effect might be deleterious, but the selection of samples from an area of comparatively well-nurtured trees, and the fact that these trees are growing under Immortelle shade, virtually exclude the possibility

of sunshine appearing as a yield depressant in the present study. Yields positively correlated with rainfall accordingly must be regarded as being enhanced by increased rainfall and not by decreased hours of sunlight; indeed, it is possible that a shorter period of sunshine is mildly deleterious, but not sufficiently so to out-weigh the beneficial effect of increased water supply. Yields which are negatively correlated with rainfall may possibly be regarded as deriving some benefit from extra illumination as well as from decreased water supply. If duration of sunlight were a factor of major importance in determining the yield pattern, it is to be expected that trees which experience the beneficial effects of both rainfall and sunshine in the same year would show a yield pattern more highly correlated with "rainfall" than trees which benefit from rainfall in the years when they gain nothing (or even lose) on account of reduced sunlight. However, the correlation coefficients of the "positive" and "negative" groups do not differ significantly whether "current season," "previous season," or their averages are compared, and there is accordingly good ground for assuming that in the present series of samples the observed relationship between yield pattern and rainfall has not been seriously disturbed by variations in the annual duration of sunshine.

"Residual" variation in yield

When the divergences from the respective regression lines in Figs. 2, 3, 4 and 5 of the actual yields of the "positive" and "negative" rainfall-correlation groups are averaged for each year to which they jointly refer, the values, as noted above, are in the first case positively and in the second negatively correlated with rainfall of the dry season (January to April inclusive) immediately preceding the crop under reference (Fig. 10). It would seem most likely that the weather of this period exercises its main influence in determining the extent of accumulation of reserves of nutrients prior to the inception of flowering.

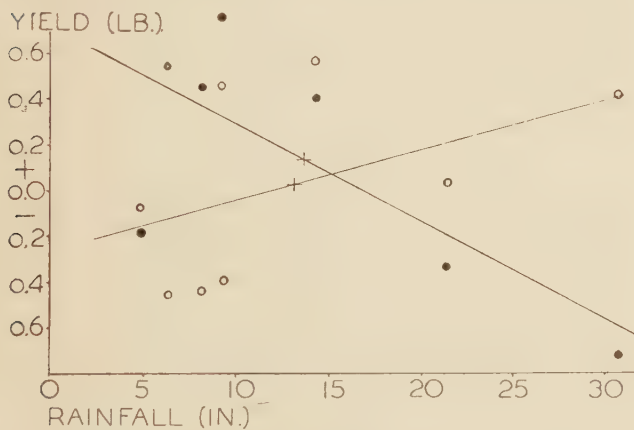


FIGURE 10

Relationship between yield-fluctuation not correlated with annual rainfall and total rainfall of the months January, February, March and April of the dry season preceding. Open circles represent yield divergences from the regressions on rainfall of the positively correlated groups (Fig. 2 and Fig. 4), solid circles the yield divergences from the regressions on rainfall of the negatively correlated groups (Fig. 3 and Fig. 5).

The divergences of yields in these two rainfall-correlation groups from their respective regression lines on rainfall as shown in Fig. 10 form complex and widely different patterns.

The pattern presented by the "residual" yield of the yield-group positively correlated with rainfall is positively correlated with rainfall during the month of September in each year (Fig. 11; $r = +0.813$, $P = 0.02$). It is probable that this correlation reflects the influence of rain during a critical period of pod development, whether wholly in September or partly in September and partly in the following month.

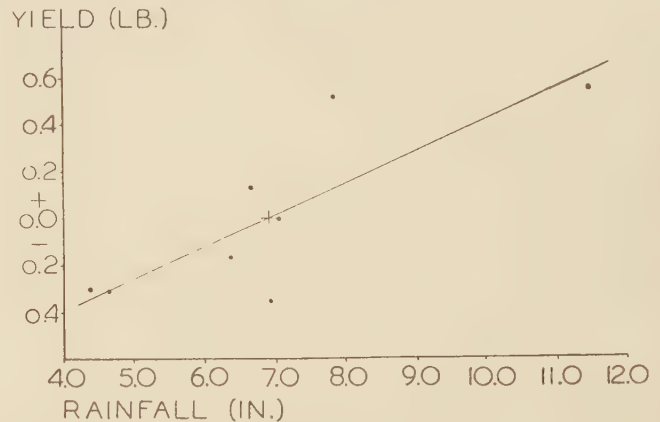


FIGURE 11

Relationship between yield-fluctuation of the "positively correlated" group not correlated with rainfall of the preceding dry season and total rainfall during September of the corresponding crop season.

If, in turn, the divergences of the actual values from the regression line in Fig. 11 are tabulated a further pattern of fluctuation emerges. If an appropriate correction is applied to the data it can be shown that they are positively correlated with rainfall during July and August (Fig. 12; $r = +0.75$, $P = 0.05$). The correction is applied to remove a downward trend of divergences from the regression line: the tenth crop season (1949-1950) is taken as the year of origin and 0.12 lb. for each year of age before this year is deducted from the recorded value, and correspondingly, an addition is made at the same rates (0.12 lb., 0.24 lb., 0.36 lb., etc.) to the values recorded later than this year. The rainfall values used in the calculation were "smoothed" by averaging the values for successive years listed in the Appendix. It is suspected that the single aberrant value in Fig. 12, that of the seventh crop season, reflects the influence of exuberant juvenile fluctuation mentioned earlier.* It is not at present clear what mechanism can account for the downward trend in the divergences from the regression line.

The pattern presented by the "residual" yield of the yield-group negatively correlated with rainfall agrees with the foregoing in showing a transition with age from divergence above the regression line to divergence below it, but differs in that the directional movements of yield divergence parallel those of rainfall during the period from the end of November to the end of March in the corresponding ("current") crop season. The degree of fluctuation, however, is feeble in relation to the corres-

* Followed through a further analysis the residual variation of the "positively correlated" yield group was found to be negatively correlated with the same rainfall values ($r = -0.73$, $P = 0.05$) with the value for the seventh year still aberrant. This correlation suggests that, even in the positively correlated yield group, unduly heavy rain in the wettest part of the wet season may exercise a mildly depressing effect on yield.

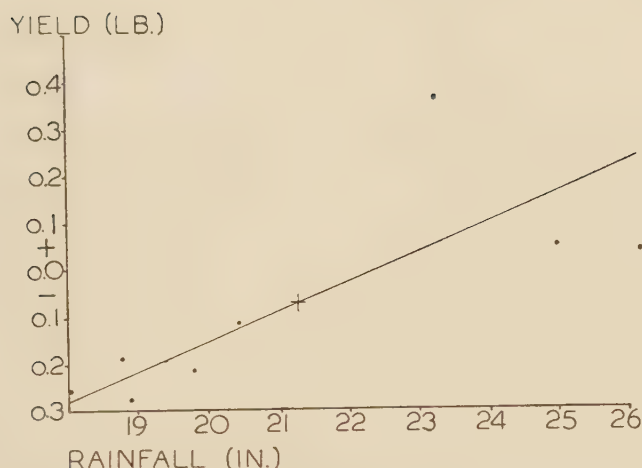


FIGURE 12

Relationship between adjusted yield-fluctuation of the "positively correlated" group not correlated with September rainfall and "smoothed" total rainfall in July and August in the corresponding crop season.

ponding fluctuation in rainfall and it would appear that a buffering factor is present. This was removed by applying a correction of 0.136 lb. for each year of age, beginning with the seventh (1946-1947 crop), adding the correction to the recorded divergence value in years when the rainfall between 30th November and 31st March was less than 20 inches, and subtracting it from the recorded value in years when rainfall in this period exceeded 21 inches. No correction was applied when the rainfall was between 20 and 21 inches.

The set of residual yield values so obtained is almost perfectly negatively correlated with rainfall in this period (Fig. 13; $r = -0.98$, $P = 0.01$). It is evident that the adverse effect of a "wet" early dry-season on the crop

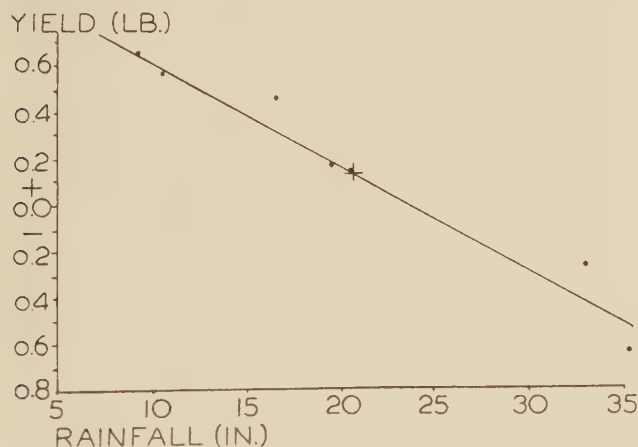


FIGURE 13

Relationship between adjusted yield-fluctuation of the "negatively correlated" group not correlated with total rainfall of the dry season (January to April) preceding crop, and total rainfall, December to March inclusive, during the corresponding crop.

is appreciable. The mechanism which buffers the response to fluctuation in early dry-season rainfall is not at present known.

General conclusions

The present study has been concerned only with yields of cacao trees at a specific group of sites and within a

specific range of rainfall variation. Apart from two transient disturbing elements, it is possible to account for almost all the variation in yield from year to year and from tree to tree by invoking differences in soil nutrient status and "behaviour" under different monthly water regimes. The two disturbing elements observed during the period of observation have been, firstly, an apparent tendency to instability of cropping associated with growth in the first seven years, and secondly, the disruptive effect of heavy pruning.

The point which emerges most forcibly from the various correlations of yield with rainfall is that any pronounced feature of rainfall at any time is reflected in the current or the following crop. Moreover, at the sites studied, it appears that the trees must enjoy only comparatively short periods of growth at an optimum moisture level, yet at such levels, if the yielding behaviour of trees of plus-and-minus yield correlation is a reliable guide, a very pronounced increase in yield may occur. If this is evident in the yield behaviour of the relatively superior trees included in the samples, the inference appears inescapable that suboptimal water relations of cacao in Trinidad as a whole are a major limiting factor on yield. The complete answer to the problem requires the planter to provide himself with means of controlling water supply, and a means of determining what treatment is needed at specific groups of sites. In both endeavours he would inevitably need guidance.

There is no indication that an alternative answer of comparable effectiveness is to be obtained by genetical methods. There is, however, no doubt that a step in the right direction can be taken by the selection of "tolerant" trees as parent material, and that a further step of substantial economic value can be taken by using, at planting, the type of tree calculated to exploit the prevailing conditions most effectively.

Finally, it is evident that whether a solution is sought along either of the above lines, or along both, it is important that a sufficiently reliable but more rapid means of determining the response of each individual tree to changes in its own small environment should be devised, in order that any required amendment can be applied in good time.

Acknowledgments

The writer's warmest thanks are tendered to Dr. A. L. Jolly for making available the yield data of Cheesman Field, and to Mr. C. de Verteuil for supplying the rainfall records of Santa Maria Estate, Gran Couva.

Summary

An analysis is made of the yields of six samples of cacao trees over a period of years. The samples include five pickets each of two high-yielding clones and one relatively low-yielding clone, and three sets of nine pickets from a high-yielding area.

The yield variation, after an initial period of about four years, normally comprises two elements, an increase in yield accompanying increase in age and a multiple correlation with rainfall.

Differences in the rate of yield-increase with age are attributed to an interaction between fertility of the site and the length of time in each year for which the tree can make unimpeded growth.

Differences in the type of correlation between yield pattern and rainfall are attributed to an interaction between

rainfall and soil at the site, with special reference to its water-retaining capacity and to the effect of different soil moisture levels on utilisation by the tree of nutrient elements.

A general scheme is formulated in which the position of pickets of each correlation group with regard to the effects of water deficiency and water excess is shown in relation to the range of annual rainfall values recorded in this field.

The yield variation which remains after the effect of yield increase with age and relationship with annual rainfall have been deducted shows a correlation with rainfall of the dry season immediately preceding the crop season. This correlation is positive in the group with yields positively correlated with annual rainfall, and negative in the contrasting group.

Further residual variation in annual yield after the preceding correlation has been allowed for, in the group with yields positively correlated with rainfall, shows firstly a positive correlation with September rainfall during the crop season in reference, and secondly, if a correction is applied to the data, a positive correlation with rainfall in July and August.

The residual variation in annual yield in the group with yields negatively correlated with rainfall, when corrected to offset a buffering effect of increasing magnitude with age, is found to be almost perfectly correlated with rainfall from the beginning of December to the end of March in the corresponding crop season.

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Appendix

Yield for crop season beginning in June and ending in May (lb. dry cacao)

Clone and block No.	1945-1946	1946-1947	1947-1948	1948-1949	1949-1950	1950-1951	1951-1952	1952-1953	1953-1954	1954-1955	1955-1956
89	4.0	3.0	7.0	4.6	11.5	5.5	11.9	19.9	21.6	11.3	18.5
189	5.4	1.6	4.4	3.6	5.5	4.0	5.3	7.9	6.4	6.7	9.4
289	8.3	6.4	12.3	12.8	16.1	5.5	14.3	14.1	15.8	10.9	12.4
389	8.8	4.5	10.9	11.3	16.4	6.3	14.6	15.9	20.6	17.1	15.7
489	6.5	4.6	13.8	4.8	12.6	8.9	7.3	11.8	11.5	6.9	11.0
95	6.6	3.4	8.8	10.3	5.4	4.3	5.4	7.3	5.4	2.9	3.1
195	9.8	3.4	4.3	7.5	4.5	5.3	10.0	5.4	3.3	4.3	3.6
295	6.4	3.8	2.5	7.0	12.5	8.8	10.0	7.3	8.6	7.9	6.9
395	11.3	9.5	4.3	6.4	8.8	5.0	6.1	7.3	10.1	6.2	6.4
495	7.1	5.8	3.5	8.4	7.3	7.1	4.0	7.3	7.0	6.6	8.3
I	2.9	0.4	0.0	0.0	0.5	1.9	0.1	0.1	1.5	1.0	0.8
101	7.0	3.7	2.5	2.9	1.3	4.0	1.4	0.3	1.3	3.0	0.0
201	0.1	0.5	0.0	0.3	0.0	0.6	0.6	0.1	0.1	1.3	1.0
301	1.5	0.1	0.5	0.6	0.8	2.9	2.8	1.0	1.6	1.6	4.1
401	0.1	1.0	1.5	2.6	2.4	3.3	2.8	3.5	1.8	3.8	3.8
476	3.1	1.3	1.4	4.9	5.6	7.4	6.4	7.5	8.1	5.4	9.6
477	2.6	0.1	2.4	4.6	4.4	2.5	4.6	4.4	3.6	6.1	3.1
478	2.4	0.8	2.3	2.5	3.4	2.4	2.1	4.1	2.5	2.8	2.5
485	0.3	2.0	7.9	11.3	6.5	3.8	7.3	10.4	6.0	1.7	6.0
484	8.1	8.8	8.5	6.3	8.1	6.8	5.9	9.1	9.4	8.0	10.4
483	0.9	0.9	0.5	3.8	1.6	4.5	5.6	2.6	3.1	1.4	3.3
492	2.3	1.3	4.0	5.0	4.3	3.9	4.1	2.1	3.5	2.9	6.5
493	3.3	0.5	1.3	2.6	7.1	2.0	1.5	4.1	2.1	3.3	4.0
494	1.6	0.9	1.3	2.6	5.8	4.6	3.3	6.0	4.8	4.6	7.4
437	1.1	0.0	0.6	3.5	1.8	3.6	2.6	1.1	2.9	1.1	1.6
436	0.0	0.5	0.1	0.5	0.3	2.1	0.3	0.8	0.8	0.8	1.4
435	4.9	2.4	4.4	5.9	5.4	4.9	5.0	5.4	6.5	3.0	4.4
448	5.0	3.1	4.9	9.1	10.0	5.8	7.8	9.9	8.0	9.0	8.6
449	5.1	2.1	6.6	5.0	5.8	4.4	4.5	4.6	5.1	1.6	3.3
450	0.3	1.4	4.8	6.8	6.6	6.4	7.6	3.5	11.3	3.1	2.0
453	4.0	1.5	1.1	7.6	6.8	5.6	5.3	8.3	10.1	1.9	11.4
452	1.0	1.8	3.9	3.3	2.6	2.4	2.1	3.3	2.9	3.9	2.5
451	0.8	0.0	1.8	2.3	2.0	3.0	2.1	2.8	2.4	3.9	2.9
467	0.8	1.4	6.6	9.1	7.3	6.1	3.9	2.6	6.4	2.5	6.9
466	1.4	1.6	4.5	2.6	2.6	2.5	3.1	1.0	4.4	0.2	7.6
465	2.1	2.9	4.4	3.1	4.0	2.9	4.4	4.1	4.8	1.7	6.6
478	2.4	0.8	2.3	2.5	3.4	2.4	2.1	4.1	2.5	2.8	2.5
479	7.0	2.5	5.3	7.8	11.4	9.4	7.8	6.1	8.3	6.8	10.2
480	3.1	1.9	6.5	7.6	8.5	9.1	9.9	8.0	14.3	4.1	11.7
483	0.9	0.9	0.5	3.8	1.6	4.5	5.6	2.6	3.1	1.4	3.3
482	1.5	0.8	1.3	0.8	3.0	2.1	2.3	1.6	2.1	0.1	2.4
481	4.0	3.0	2.0	1.9	3.4	4.1	4.6	4.0	3.0	2.4	6.6

ANNUAL RAINFALL IN INCHES

January to December				May to April		
1944	...	...	85.29	1944-45	...	89.83
1945	...	...	81.82	1945-46	...	77.92
1946	...	...	92.31	1946-47	...	91.25
1947	...	...	71.98	1947-48	...	77.99
1948	...	...	93.94	1948-49	...	85.94
1949	...	...	90.47	1949-50	...	105.42
1950	...	...	102.74	1950-51	...	112.13
1951	...	...	105.42	1951-52	...	79.63
1952	...	...	70.16	1952-53	...	74.40
1953	...	...	74.50	1953-54	...	75.94
1954	...	...	79.35	1954-55	...	80.90
1955	...	...	82.33			

ANNUAL SUNSHINE IN HOURS

January to December			
1946	...	...	2,580.4
1947	...	...	3,028.2
1948	...	...	2,661.4
1949	...	...	2,700.9
1950	...	...	2,420.6
1951	...	...	2,467.8
1952	...	...	2,900.1
1953	...	...	2,496.6
1954	...	...	2,513.4
1955	...	...	2,510.0

RAINFALL

During specific periods of the year

Crop season	Year	September (in.)	December-March inclusive (in.)	January-April inclusive (in.)	July-August inclusive (in.)
1946-47	1946	4.66	16.61	9.46	25.07
1947-48	1947	6.95	20.58	8.40	21.33
1948-49	1948	11.46	9.36	14.41	19.59
1949-50	1949	4.42	33.00	6.41	30.24
1950-51	1950	6.40	35.27	21.36	21.88
1951-52	1951	7.05	10.62	30.75	17.77
1952-53	1952	6.67	19.73	4.96	18.31
1953-54	1953	7.85		9.20	19.18
	1954				18.57

Deficiency Levels of the Major Nutrients in Cacao Leaves

by
D. B. Murray

THE symptoms associated with deficiencies of mineral nutrients in cacao leaves have been described and illustrated by Maskell, Evans and Murray (1953). Leaf material from plants growing in the various culture solutions was sampled using the second leaf from the apex in the terminal hardened flush. The material was oven-dried, ground and analysed for nitrogen, phosphorus, potassium, calcium and magnesium. The results follow in Table I.

TABLE I
Leaf analyses as % dry weight

	Ash	N	P ₂ O ₅	K ₂ O	CaO	MgO
Control	...	6.6	1.68	0.41	1.76	1.40
Minus N	...	11.6	0.94	1.48	4.24	1.07
„ P	...	9.9	2.06	0.17	2.27	1.39
„ K	...	7.0	2.19	0.61	0.66	1.75
„ Ca	...	8.3	2.15	0.45	2.62	0.53
„ Mg	...	9.9	3.04	1.28	4.43	0.49

These figures show not only the lowered levels of the particular nutrient deficient in the culture solution as compared with the control plant but also the effect on the general nutrient balance of the leaf.

A considerable amount of work has been devoted to the investigation of the use of the results of leaf analysis for the determination of the nutrient status of the tree. The ideal aimed at is to be able to use leaf analysis as a means of controlling fertiliser application in the field but so far the results have not been very encouraging for several reasons.

Some of these have been described by Fennah (1953) in connection with sampling techniques. Briefly the nutrient status of the leaf is affected both by its age and by the light intensity at which it is growing. Taking one element, potassium, as an example, the level of potassium in the leaf as percentage dry weight falls with increasing age. On the other hand increasing shade leads to an increase in leaf potassium. The problem is therefore to specify standards and no single sampling value is likely to prove adequate as stressed by Fennah. It would theoretically be necessary to have standard values for leaves of all ages growing under all conditions from no shade to heavy shade. Only from such figures would it be perhaps possible to determine departures from optimum values due to particular nutrient deficiencies.

The value of the information given in Table I is therefore of less interest for the actual levels of any nutrient than in demonstrating changes in general nutrient balance. The effects of the deficiencies on some of the nutrient ratios are given in Table II.

TABLE II
Nutrient ratios

	N/P ₂ O ₅	N/K ₂ O	K ₂ O/P ₂ O ₅	K ₂ O/CaO	K ₂ O/MgO	CaO/MgO	Sum of bases
Control	4.08	0.95	4.30	1.25	2.18	1.73	3.97
Minus N	0.64	0.22	2.86	4.00	3.82	1.06	6.42
„ P	12.22	0.92	13.30	1.64	2.50	1.52	4.57
„ K	3.16	3.32	1.98	0.46	0.65	1.72	3.43
„ Ca	4.78	0.82	5.82	4.76	3.20	0.64	3.97
„ Mg	2.38	0.69	3.46	9.10	14.80	1.60	5.22

This table shows that with nitrogen deficiency, for example, not only are the N/P₂O₅ and N/K₂O ratios markedly reduced from the control values as would be expected, but that the K₂O/P₂O₅ ratio is also reduced while the K₂O/CaO ratio is increased. The effect of nitrogen deficiency on base accumulation is also obvious. These phenomena of antagonism are to be expected in nutrient unbalance but are stressed here as being more

informative of nutrient deficiency than a single figure for the level of the particular nutrient.

The range in nutrient levels produced in this experimental work is far greater than has ever been found in the field and consequently the ratios differ widely. When the nutrient levels of poor yielding trees in the field are to be compared with high yielding trees, with a view to fertiliser recommendation, the ratios however are so much closer

that the problems of sampling in regard to leaf age and light intensity become of such importance that diagnosis from

a single sample selected by eye becomes well nigh impossible.

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Nutrient Uptake by Excised Cacao Roots—A Micro Technique

by

T. A. Jones, G. Havord, and G. K. Maliphant

PRACTICALLY no work has been reported on the relationship between the morphology, growth and mineral composition of cacao roots and the performance of the tree. In this connection the crop logging procedure for cacao described elsewhere in this report, necessitated study of the nutrient uptake by cacao roots, simply and directly.

As a first step in this study the method of Humphries (1950) was adopted. This involved an initial chemical analysis of a sub sample of excised roots, followed by subsection of a further sub sample to a constantly aerated complete nutrient solution. After a fixed interval the roots were removed from the nutrient solution and a final chemical analysis of them undertaken. Humphries has shown that by this treatment, excised roots from barley and other plants grown in sand and nutrient cultures lacking N, P or K absorbed the missing element preferentially. He also obtained indications that the technique might reflect deficiencies with roots grown in soil. It was found, however, that the practical difficulties of obtaining a suitable, sufficiently large root sample from cacao experimental plots precluded the extensive use of the method.

A technique was therefore developed which involved very small quantities of root material. After preliminary experiments had given encouraging results, the technique was tried on cacao seedlings grown in sand and nutrient solution cultures. ICS 39 open pollinated seeds, three per pot, were grown in coarse sand in 1 gallon pots. Six treatments replicated four times and arranged as four randomised blocks were formulated by omitting, one at a time, the five nutrients N, P, K, Ca and Mg from Hoagland's solution. The control treatment was complete Hoagland's solution. In preparing the nutrient solutions the deficient cations were replaced by sodium and the deficient anions by chloride or sulphate. Trace elements (iron as iron "versenate") were supplied to each treatment.

After nearly 9 months growth all except the control plants had developed characteristic deficiency symptoms. The plants were then carefully excavated. It was found that three types of root could be distinguished:

- (1) White fleshy roots, obviously a new flush.
- (2) Fine fibrous whitish roots, turning brown.
- (3) Thick dark brown suberised, sometimes woody roots.

Choice of sampling material

It was necessary in the first instance to know which of the three types of roots provided the best type of root sample for nutrient absorption studies. Type (1) was clearly an active feeding root and capable of nutrient absorption as demonstrated by Humphries. Types (2)

and (3) were increasingly aged. Samples of each type of root were cut from the plants in each pot and washed rapidly with distilled water. They were dried between filter papers and 200 mgm. samples weighed and placed in 50 ml. beakers.

A five times dilution of Hoagland's complete nutrient solution (4 ml.) was added and the beakers left in a moisture saturated atmosphere in the dark for 24 hours. By means of a pipette 0.5 ml. of solution was then withdrawn and magnesium estimated semi-quantitatively on a spot plate using suitably diluted magneson reagent. The remaining 3.5 ml. (approximately) was diluted to 35 ml. and analysed for nitrate N and phosphate colorimetrically and for K and Ca flame photometrically. Results for N, P, K and Ca were statistically analysed.

In some cases nutrients were apparently taken up by the roots, in others exuded. The amounts taken up or exuded by roots of each treatment are shown in Fig. 1 as percentages of the quantity of the particular nutrient originally present in the diluted solution. Differences statistically significant at $P = 0.05$ are also indicated.

There was a striking similarity between results with white fleshy roots and with fine fibrous roots. Results with dark brown roots showed some discrepancies and in most cases uptake or exudation was least with these roots. In general roots from plants lacking N, P, K and Mg clearly tended to absorb these nutrients preferentially although appreciable uptake of Ca also occurred with roots lacking K. In all cases where potash was adequate roots exuded potash, preferentially even to Ca uptake with calcium deficient roots.

Comparison of excised and non-excised samples

Non-excised root ends from the same plants as used in the previous experiment were immersed for 24 hours in 4 ml. of the diluted Hoagland's solution. The solutions were then subjected to the same analytical procedure as described in the previous section. There were not enough roots available to provide four replicates per treatment and statistical analysis of results was not possible. The general trend of results was, however, similar to that obtained with excised roots, though there were a few discrepancies.

Application of technique to field experiments

The relative success achieved by the technique with plants growing in sand cultures justified an attempt on mature cacao trees growing under controlled field experiments. White roots from cacao trees growing in Expt. I at River Estate (Havord 1953) were excavated at the time of the September leaf and root flush and subjected to the same technique as already described. Four replicates

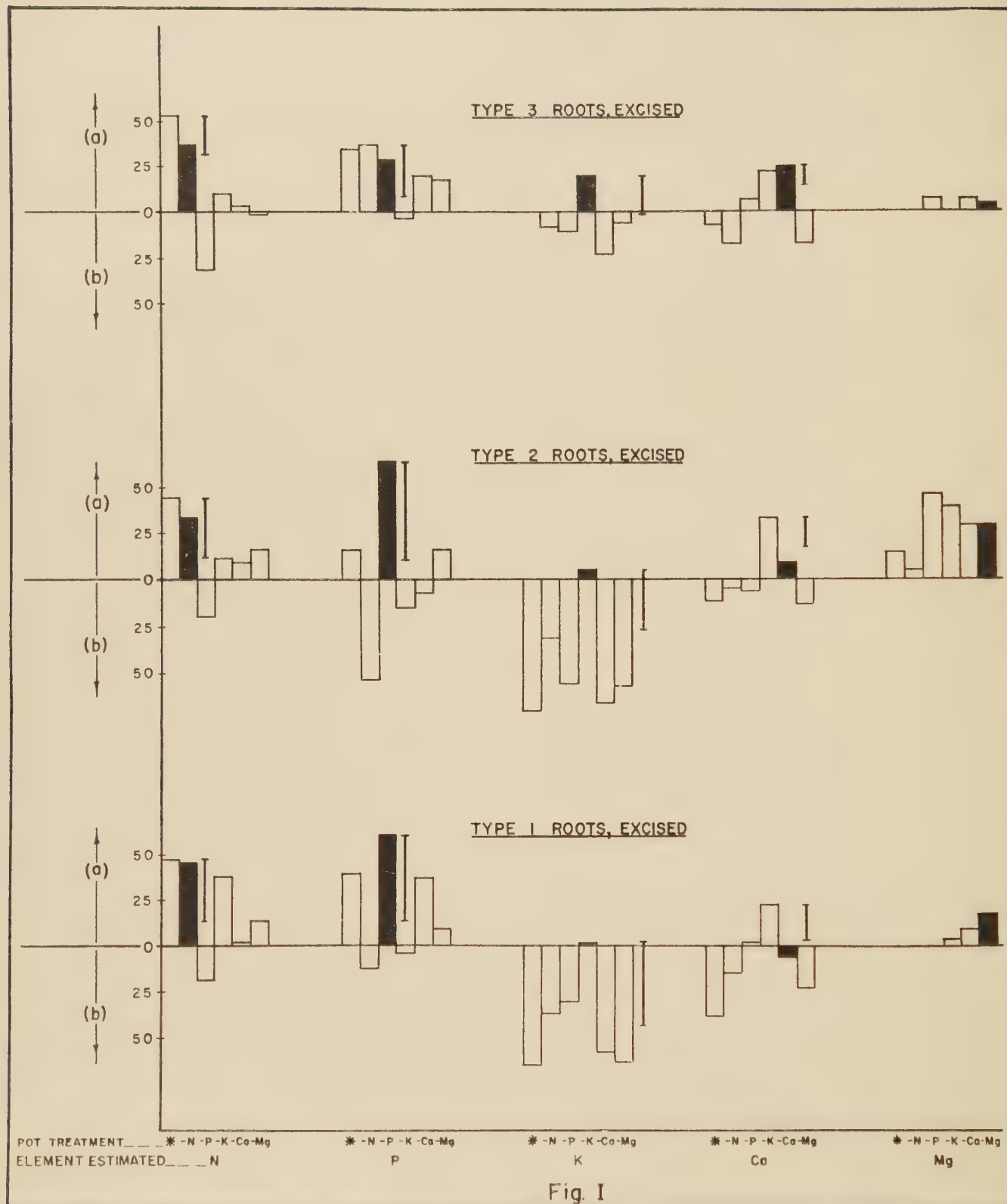


FIGURE I

(a) Absorption by roots of element estimated as percentage of that element in original nutrient solution.

(b) Exudation by roots of element estimated as percentage of that element in original nutrient solution.

* Control, i.e. full nutrient solution.

I Significant differences ($P = 0.05$).

from trees growing under the treatments NPK, PK, NK, NP, O (i.e. treatments —O, —N, —P, —K, —NPK) were used all from wide spaced unshaded plots. Amounts of nutrients taken up or exuded by plants of each treatment are shown in Fig. 2 as percentages of the quantity of the particular nutrient originally present in the diluted nutrient solution.

The figure illustrates that roots of trees not receiving P fertiliser absorbed significantly more of this nutrient than roots from trees fertilised with P. No significant differences in uptake of N or K were observed although all roots exuded K. Calcium was exuded by roots from trees receiving NK and NPK fertilisers but was absorbed by those receiving NP and PK and by control plots.

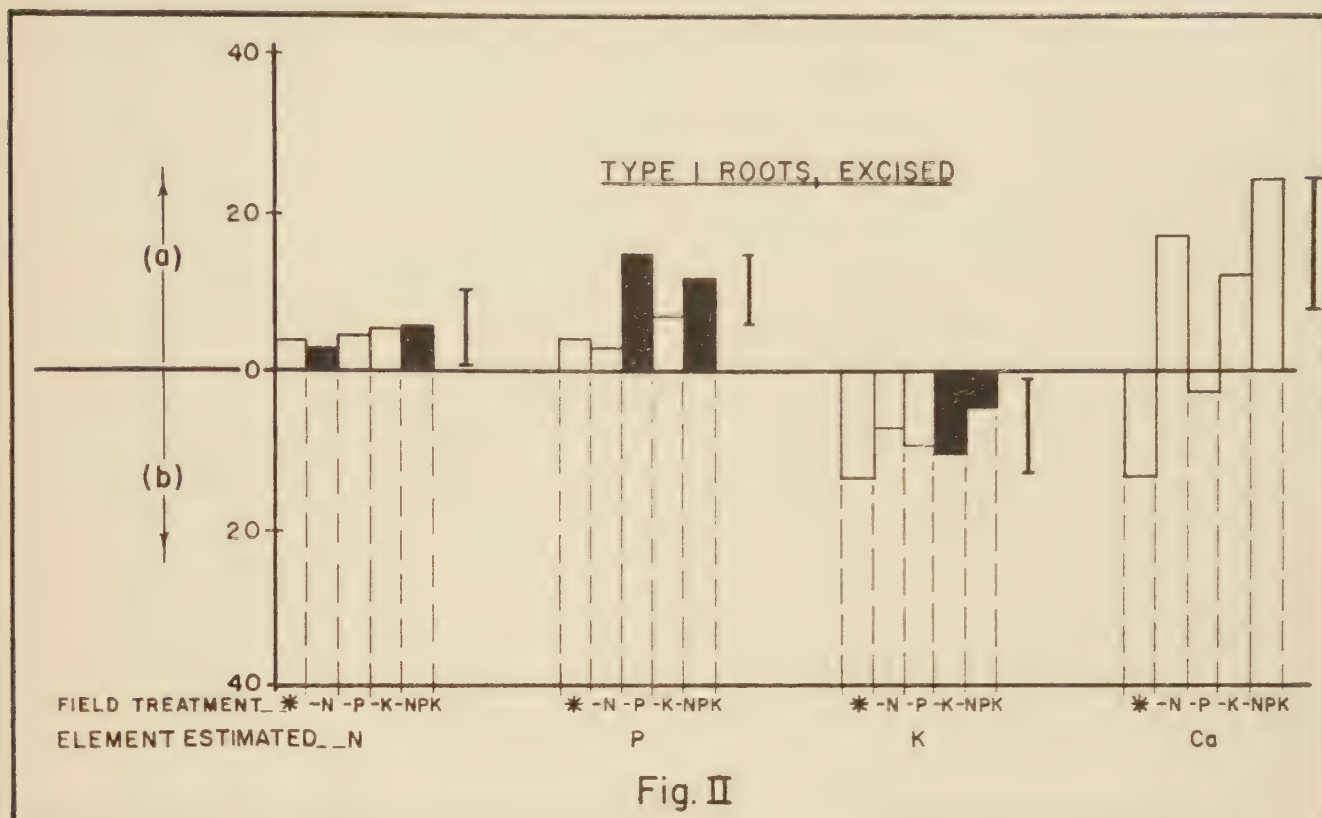


Fig. II

FIGURE 2

- (a) Absorption by roots of element estimated as percentage of that element in original nutrient solution.
- (b) Exudation by roots of element estimated as percentage of that element in original nutrient solution.
- * Control, i.e. full NPK fertiliser application.
- I Significant differences ($P = 0.05$).

Discussion

Since water and nutrient absorption by roots only occurs through young actively growing tissue, it was expected that white roots would be the best material to use in studying nutrient uptake. The exchange properties of root surfaces (Mehlich and Drake 1955), however, lead to nutrient adsorption even when the surfaces are no longer capable of nutrient absorption. No measurements of the ion exchange capacity of cacao roots have been made. Values for other species suggest that the quantities of nutrient uptake in these experiments could be accounted for solely by ion exchange. It was therefore essential to the success of the technique that white roots displayed the property of nutrient uptake to a degree as high if not higher than occurred with brown roots which were considered no longer capable of nutrient absorption. In these circumstances and at this preliminary stage of the study it was then not necessary to know whether the observed phenomena predominantly involved absorption or adsorption.

The ability of white roots when excised to function in a similar manner to roots attached to the trees is a positive indication that the root sample is still capable of acting as a living organism during the course of the experimental procedure. This is additionally fortunate in view of the practical simplicity of routine investigation with excised roots rather than with roots still attached to the plant in the soil.

Results of absorption by roots in sand cultures clearly demonstrated the known deficiencies in the nutrient solutions, particularly deficiencies of N, P and K. Results for Mg were less satisfactory owing to the limitations of the analytical procedure. These deficiencies were of course extreme and not necessarily to be expected in the field. Results of absorption by roots from field plots in some cases showed good agreement with field treatments. Thus roots from trees not receiving phosphate fertiliser absorbed significantly more phosphate than roots of trees which had received phosphate. Roots from all field treatments exuded potash. This is not surprising since

unshaded field plots show no response to potash fertiliser and since roots grown in sand culture adequately supplied with potash also exuded potash. Results with uptake of N were less satisfactory. In pots, roots lacking N absorbed no more N than roots from the control treatment. Similarly roots from field treatments not receiving nitrogen fertiliser absorbed no more nitrogen than those roots from fully fertilised plots. It is possible that better results for N uptake will be obtained by using ammonium N instead of or as well as nitrate N in the nutrient solution, since there is evidence (Butters 1953) that young cacao is ammonophilic.

The absorption of Ca by roots from field plots not receiving potash (i.e. NP and O treatments) paralleled the result obtained with roots grown in sand culture. On the other hand absorption of Ca by roots from field plots

lacking N (i.e. PK treatment) was not observed in pot material. There appears to be an inter-relationship between K and Ca in the behaviour of cacao roots to nutrient solutions which clearly requires further investigation before comment is possible.

Considerable refinement of technique is necessary before the present approach to root absorption can be acceptable as a working tool in the study of cacao tree nutrition. Some of the anomalies in the current work for example might be due to lack of control of the sugar status of the living cells (Humphries 1956). The results obtained however are sufficiently consistent to justify continued attention and improvement of the method. It is hoped that research workers on other crops may consider the procedure suitable for their needs, since it is clearly adaptable to any root system.

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Leaf Symptoms of Deficiencies of Calcium and Magnesium in Cacao

by
G. Havord

DIFFERING descriptions of leaf symptoms of calcium and magnesium deficiency in cacao have been given by Maskell, Evans and Murray (1952), working in Trinidad, Greenwood and Djokoto (1952) in the Gold Coast; and Machicado and Alvim (1953) in Costa Rica. In connection with other work, cacao seedlings (ICS 39, open-pollinated) were grown in pots in the greenhouse (three plants per pot) in coarse sand and Hoagland's nutrient solution (Hoagland and Broyer 1936) with added trace elements and iron versenate. Treatments applied were: (i) full nutrient solution; (ii) lacking nitrogen; (iii) lacking phosphorus; (iv) lacking potash; (v) lacking calcium; and (vi) lacking magnesium. The deficient nutrient solutions were prepared by replacing the appropriate cations by sodium and the appropriate anions by chloride or sulphate. Four replicates of the six treatments were arranged in four randomised blocks. Characteristic leaf deficiency symptoms developed in each treatment: those of nitrogen, potash and phosphorus were similar to those described by the workers cited, whilst those of calcium and magnesium afforded additional evidence in these disputed cases.

Calcium deficiency

Maskell, Evans and Murray, in describing calcium deficiency symptoms, write:

"The young leaves show a pattern of white spots on the lamina, and tip and marginal necrosis, which is most severe in the older leaves, occurs. In severe deficiency the leaves are shed prematurely and young buds that develop soon die back. In the older leaves, tip and marginal scorch progress rapidly, leaving an oak-leaved pattern of unaffected lamina within the rapidly advancing necrotic zone. There are no islands of necrotic tissue in advance of the necrotic zone and this, together with the white spots on the young leaves and the thickened mid-rib, differentiates calcium deficiency from magnesium deficiency—which is the only other deficiency with which it might conceivably be confused." Machicado and Alvim state*:

"The cacao plant appears to be extremely sensitive to lack of calcium. From the start the plants showed severe symptoms. The cuttings only succeeded in reaching the first leaf flush and died in a short time. With seedling plants, retarded flushing was soon observed. The few leaves which appeared were small and feeble. These plants were accordingly transferred to a complete solution. They soon reacted and the next flushes were normal. After the third flush calcium was again eliminated from the solution, and the plants once

more showed deficiency symptoms. In a short time growth stopped and the newest leaves began to show necrotic spots which spread into the interveinal region and formed localised spots especially at the base of the lamina and near the mid-rib. In general the necrosis began long before the leaf reached full maturity. As the deficiency became more serious the necrosis reached the main veins and the secondaries. The margins of the lamina, like the tip, did not show necrosis. They simply showed a withdrawal of moisture which gave the edges a continuous crinkling. This condition was followed by shedding of the affected leaves."

Greenwood and Djokoto did not describe calcium deficiency symptoms.

In the present experiment, symptoms corresponding to those described by Maskell, Evans and Murray were consistently obtained, with the exception that the white spots they mention were not observed. The symptoms occurred first on the older leaves. They were very similar to symptoms of potassium deficiency, as indeed are those described by Maskell *et al.* The symptoms are shown in the colour plate.

Magnesium deficiency

Maskell, Evans and Murray describe these symptoms as follows:

"The first symptoms of magnesium shortage appear in the older leaves, which develop tip and marginal necrosis. With increasing severity of the deficiency, similar symptoms occur even in the young leaves. The necrosis commences as a discoloration of the vascular strands composing the lateral veins where they change direction and become parallel to the leaf margin. The marginal interveinal areas become pallid and necrosis soon begins. The interveinal areas quickly fuse to produce a continuous tip and marginal scorch which advances more rapidly in the interveinal region. Very frequently, though not invariably, pallid areas formed in advance of the main scorched area become necrotic, and in severe deficiency the portion of the lamina inside the main belt of invading necrosis may have several isolated necrotic areas. In mild deficiency these internal isolated areas may not occur, in which case an oak-leaved pattern of the unaffected part of the lamina similar to that produced by lack of calcium results. This unaffected part of the leaf is invariably pale green, presumably due to the effect of magnesium deficiency on chlorophyll production, and is thus in marked contrast to potassium deficiency where the unaffected part of the lamina is generally a healthy green. There is present

* Author's translation

a similar yellow zone in advance of the developing necrotic areas: this zone is frequently, though not invariably, a brighter yellow than in the case of potassium deficiency."

Machicado and Alvim's account reads*:

"The first manifestations of magnesium deficiency began on the oldest leaves. A very slight chlorosis could be seen in the interveinal areas accompanied by small spots which soon extend to constitute severe

* Author's translation.

necrosis. The necrosis, however, did not reach the veins, the tip, or the edges of the lamina. Magnesium deficiency symptoms could not be observed on plants propagated vegetatively, as all the magnesium deficient plants died before showing deficiency symptoms. It is noteworthy that Maskell, Evans and Murray working with cuttings described magnesium deficiency symptoms very different from those encountered in this work. They obtained chlorosis followed by necrosis of the leaf margin, and from the photographs published the symptoms are very like those of potassium deficiency."



— Ca

Greenwood and Djokoto write:

"Leaves of the first flush were normal in shape, uniformly yellow-green with light green veins. They gradually turned yellow; margins and tips developed scorch when about seven weeks old and shedding began soon afterwards. In the second flush, leaves were small, whitish green or translucent and had a marked downward tip curl. All were shed within 20 days of emergence." They summarise, however, thus: "Indeterminate; general chlorosis and shedding of all leaves."

The symptoms obtained in the present work are illustrated in the colour plate. They correspond exactly with those found by Machicado and Alvim and are quite different from those reported by the other investigators. These symptoms too appeared first on the oldest leaves, and (with the exception of nitrogen deficiency symptoms) were the first symptoms to appear. As observed by Maskell *et al.*, additional iron supplies were necessary to counteract the development of iron deficiency symptoms in both calcium and magnesium deficiency.



— Mg

It will be seen that the discrepancies in the various symptoms observed mainly arise because of the appearance or otherwise of marginal and tip necrosis. Maskell and his colleagues and the author observed marked marginal necrosis in the case of calcium deficiency, whereas Machi-

cado and Alvim did not. Maskell *et al.* and Greenwood and Djokoto (though indefinitely) observed marginal and tip scorch with magnesium deficiency, whereas Machicado and Alvim and the author did not. It is known that cacao is particularly liable to develop tip and

marginal leaf necrosis and that this is associated with potassium deficiency, water strain, chloride toxicity and generally high salt levels in the leaf (Rodrigues 1953). It may be that other conditions in the environment are responsible for marginal necrosis in some cases, and that this may have masked other symptoms.

The isolated interveinal spots, first chlorotic and then necrotic, observed in the case of magnesium deficiency by the author and by Machicado and Alvim are characteristic of magnesium deficiency in other plants. Maskell, Evans and Murray also noted them but apparently they

were quickly obscured by the marginal necrosis.

It is noteworthy that marginal necrosis was always preceded by a yellow band wherever it occurred in the author's work and always commenced with tip necrosis and a necrotic area at the edge of the lamina between the veins; these areas then rapidly coalesced to form a continuous necrosis. These features do not appear to form a reliable basis for distinguishing the various causes of marginal necrosis as claimed by Maskell *et al.* The occurrence of marginal necrosis therefore should be interpreted with caution.

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The Nutrition of Cacao—A Programme of Research

by

T. A. Jones, G. K. Maliphant, and G. Havord

PLANT behaviour is an integrated expression of environmental conditions; only when all conditions are optimal can plant performance be optimal. Because of this, there is need in the study of plant behaviour for the scientific appraisal of a given environment and the measurement of optimal values for each constituent in that environment; this is however a complicated problem. Attempts at solving the problem with the cacao tree have been hampered in the past by the fact that the only experimental material available for study was old-established cacao plantings. On such sites it was not possible differentially to study the shade factor in the environment. The practice of using shade trees in cacao management induces the tree to photosynthesize at a low rate of energy exchange. The rate of nutrient uptake by the tree is thereby subdued and possible unfavourable factors in the environment such as limiting nutrient supply in the soil and poor soil aeration affect the general physiology of the tree less critically. In fact it is now appreciated that shade acts as a buffer against adverse environmental effects, permitting the tree to function relatively favourably albeit with less virility. In the absence of shade the tempo of the life processes of the tree is increased, the rate of demand for nutrients from the soil is increased with the consequent need for good soil aeration, and the whole tree becomes critically disposed to adverse factors in its environment. It is becoming increasingly clear that cacao is especially sensitive to adverse environmental conditions.

To elucidate the optimal environmental conditions for cacao, an elaborate group of field experiments has been initiated by the Soils Department of the Regional Research Centre at River Estate (Havord 1953 a, b). Many of the experiments include shade contrasts. They were necessarily laid down on one type of soil and under one climate, but many of the factors in the environment are experimentally varied. A start has been made with similar experimentation on a contrasting soil, and it is expected that this work will be extended in the near future.

Early yield and growth data from the older and more fundamental experiments have been published (Havord, Maliphant and Cope 1954). The experiments have now passed what is termed the "establishment phase" and are providing material for more detailed research. This research must be extremely carefully planned since the wealth of material available, if not wisely organised, would overtax available laboratory facilities.

As a result of work on cotton by Mason and Maskell and by Balls, and on sugar-cane by Clements, it is now largely possible to predict the behaviour of those crops with fair certainty. This has led to the hope that a similar

approach to cacao might be productive. That cacao is a tropical tree crop is however a complicating factor. A change in any observable or measurable feature of the trees may reflect a change in nutrient supply directly by uptake through the roots, or from storage organs, or from both these sources simultaneously. It is thus difficult to interpret unequivocally analyses of specific parts of the tree so long as the role of each nutritional entity in that part, at the particular time and under the particular environment, is not fully understood. Unfortunately, much of the internal physiology of the tree is still obscure.

To follow the behaviour of the plant under the environmental conditions to which it is experimentally subjected, a crop-logging procedure has therefore been commenced. Correlation between crop performance and a single measurable index is not expected. Neither is it intended in this work to investigate the detailed internal physiology of the plant. Rather is sought a sympathetic movement of all or many of the observed factors which will reflect the interaction between the tree and its environment. Observations made on the field experiments so far and previous work by others reveal the following facts:

(1) The response of the cacao tree to fertilisers is governed by the degree of shade. In particular nitrogenous fertilisers give much greater response with unshaded than with shaded cacao and may in fact depress yields under heavily shaded conditions (Murray 1954; Havord, Maliphant and Cope 1955).

(2) The physical conditions of the soil must be reasonably satisfactory before response to fertilisers can be expected. In particular, adequate soil aeration is a necessary requisite of maximum response to fertilisers (Hardy 1955; Havord 1955).

(3) The availability of soil nutrients especially cations, at any given time, depends not only on the quantities present in the soil, but on the particular types of soil colloid present (Brown and Noggle 1955; Brown 1955) and on its moisture content.

(4) A leaf flush occurs a few days after a flush of new roots (McKelvie 1953). These roots are active feeding roots and supply the increased demands of the leaf flush or replace demands on the tree made by the developing flush. They occur mainly in the very well aerated surface soil crumb and litter and frequently lie on the surface of the soil rather than in the soil.

(5) General leaf flushes usually occur at the beginning of the rainy season, during the drier spell usually experienced in September, and at the beginning of the dry season; that is, at those times when soil moisture and air conditions are likely to be optimal for root growth.

(6) The greatest demand for nutrients is when the tree is flushing and the new flush hardening. Cherelle wilt is most severe at the time of a leaf flush and is largely due to competition between the leaf flush and the developing crop (Humphries 1943).

Logging procedure

Based on all the foregoing considerations, the programme of logging which has been undertaken involves the measurement, at frequent intervals, of components of the tree and its environment enumerated below. The programme is so far being applied to Experiment I (shade, spacing, fertilisers) and Experiment III (mulches, trenching, clones), both planted in 1949. (For descriptions of these experiments see Havord 1953.)

(i) Soil moisture

Various techniques were considered, including gypsum blocks, neutron scattering, and tensiometers. None possessed appreciable advantages over the use of a tubular sampler to withdraw the soil sample, fitted with a plunger to extrude the sample into a tared container, and subsequently oven-drying the sample. Four replicate samples are taken weekly from the 0-3, 3-6, 9-12 and 21-24 inch layers under the four shade-spacing combinations treatments. The 160 samples per week are taken by a field team of three in about three hours. Results are plotted as three-weekly running means on a volume percentage basis using a pore-space diagram similar to that used by Hardy (1943). The frequency of sampling the top three layers is increased to thrice-weekly at the change from dry season to wet and *vice versa*, and during the September dry spell.

(ii) Nutrient supply by the soil

To date this has been studied by determining the rate of leaching and the residual amounts of the fertilisers added, by classical methods of soil analysis. It is hoped to initiate fundamental studies of the effect of the particular clay minerals and soil moisture conditions on the capability of the soil to supply different nutrients at different times.

(iii) Leaf analysis

A great deal of success has been achieved in diagnosing the nutritional status and fertiliser requirement of some crops by chemical leaf analysis. A notable example in the tropics is sugar-cane. Tropical tree crops, in particular cacao, present greater difficulties. These are due to the complicating effects outlined previously; to the effect of shade on nutrition and leaf composition; and to the irregular flushing habits of the tree which result in leaf samples of different chronological and physiological age growing on the tree at any one sampling time.

The suitability of McDonald's technique (1934) for sampling cacao leaves has been discussed by Fennah (1953), who proposed an alternative method. This method is unsuitable for the present crop logging programme, since it would involve 86,000 separate analytical determinations annually—a laboratory burden too great to accommodate in addition to the remainder of the logging procedure. A method developed by Boynton and Sands (1954) included within samples, leaves of widely differing age. It is not surprising that this method is of very restricted application.

One of the authors (G. K. M.) investigating the problem of leaf sampling of cacao, observed that differences in

mineral content of leaves from trees growing under different environmental conditions were largest when a new flush of leaves was forming. These differences are likely attributable to the nutrient demands of the tree being greatest at that time. The following leaf sampling procedure was therefore adopted and incorporated in the current research work.

Leaves immediately adjacent to an opening bud were sampled when the bud itself possessed leaves 1-3 cm. long. Samples were taken as far as possible only from the periphery of the tree. Not more than three leaves were taken from any sampling point, thereby avoiding the danger of sampling a leaf flush of an older age group. Ten leaves undamaged by insects or falling twigs formed a complete sample. The sample was analysed chemically using the methods described in the Appendix. Errors in sampling and in analytical precision also shown in the Appendix are small and indicate that leaf samples selected according to the described technique do not vary widely in physiological age. In addition, by this procedure sampling points are easily recognised in dense foliage and sampling time is accurately defined.

(iv) Bark analysis

The chemical analysis of bark samples (Humphries 1950) has been undertaken to provide a further measure of nutrient status of the tree which can be considered together with other parameters. The number of samples which can be taken periodically without seriously damaging the tree is strictly limited. In the present programme four trees in each experimental plot are sampled monthly at a height of 4 ft. from the ground. Samples are taken with a modified 1-in. steel cork borer. The four samples are bulked and chemically analysed by the methods used for leaf sampling (q.v.).

(v) Plant development data

A simple dendrometric method of measuring the weekly woody growth of sample trees in each experimental plot is used. The method is due to Goode (private communication). Two brass drawing pins, their points cut short, are fixed by waterproof glue at diametrically opposite points on the trunk or a branch of the tree. Weekly measurements of the distance between the two pins are made with a large micrometer screw gauge. Incremental and total growth rates are plotted graphically. After some months the pins may become loose; they are then replaced nearby by others and the subsequent records suitably corrected.

Fortnightly counts of the number of flowers produced, cherelles set, cherelles wilted, pods matured and reaped, and pods lost through diseases, are made at sample trees in each experimental plot. Some early results of this work have already been published (Havord, Maliphant and Cope 1955). The occurrence of leaf flushing is also noted.

(vi) Climatic conditions

Two meteorological stations on the Estate record data in the usual way.

(vii) Root studies

The most direct measure of nutrient uptake from the soil by roots may lie in some form of root analysis; but practical difficulties are great. At present studies of nutrient absorption by excised roots are yielding encouraging preliminary results. These are described elsewhere in this report.

The whole of the above logging procedure has (at the time of writing) been in operation for ten months. The sampling and recording is carried out by a field team of three. Results from this study should ultimately provide an understanding of the way in which the experimentally varied environmental factors affect the performance of cacao (especially when the technique is later extended to contrasting soil and climatic environments). In particular, precise diagnosis of those conditions which economically merit fertiliser amendments will receive special emphasis.

It is the authors' opinion that methods currently available for cacao, although adequate for detecting gross nutrient deficiencies, are insufficiently sensitive when these deficiencies are of a lower order.

That some of the combinations of factors in the experiment under study are capable of producing high yields of cacao is apparent from the fact that the best treatments have, in the past two years, yielded over 1,400 lb. of dry cacao per acre per year from trees planted in 1949.

Appendix

Analytical techniques

The following is a brief summary of the methods used in the analysis of leaf and bark material of cacao.

Cacao leaf material is hygroscopic, but it has been found if a sub-sample of the dried material is weighed within 15 minutes of its removal from a dry atmosphere, less than 1% of its weight will be absorbed, even in a 100% relative humidity atmosphere.

Bark and leaf samples are dried at 105-110°C. in 24 hours.

Ash content

Oven-dried material, 1.00 gm. (or 0.50 gm. according to the quantity available) is ashed at 600°C. in a muffle furnace for 3 hours.

For the estimation of mineral content the ashed material is extracted with 10% hydrochloric acid. The residue, insoluble ash, can for all practical purposes be considered to be silica.

Potassium, calcium and sodium

These elements are estimated flame photometrically in the acid extract of the ashed material.

Nitrogen and phosphorus

Nitrogen is estimated in the oven-dried material by a semi-micro-Kjeldahl digestion using hydrogen peroxide as the catalyst. To avoid additional ashing operations, phosphorus is estimated in the Kjeldahl residues by Denigés' (1920) method.

Magnesium

Magnesium is estimated in the acid extract of ashed material by means of an ethylene diamine tetra-acetate titration (Diehl, Goetz and Hach 1950).

The following table shows the coefficients of variation of the above analytical techniques and of the "new flush" leaf sampling technique. For comparison similar data obtained by McDonald's (1934) sampling technique are included.

Factor analysed	Coefficient of variation of analytical errors	Coefficients of variation of sampling errors	
		"new flush" samples	"McDonald" samples
	n = 54	n = 28	n = 28
Total ash	3%	6%	8%
N % O.D.M.	2%	6%	5%
P ₂ O ₅ % O.D.M.	2%	4%	9%
K ₂ O % O.D.M.	2%	8%	4%
CaO % O.D.M.	2%	12%	13%
MgO % O.D.M.	4%	10%	9%

The analytical and sampling errors in both methods are of similar order to those found in work with citrus (Reuther and Smith 1954).

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The Growth Substances of *Theobroma cacao*. I

by
R. Nichols

Introduction

THE primary reason for the examination of the growth substances of cacao was to obtain a more fundamental understanding of the problem of "cherelle wilt." Many of the fruits of cacao never reach maturity; at some stage in their life-history the pod-wall blackens and eventually the whole fruit shrivels and mummifies on the tree. The number of fruits which may be affected in this way, may reach a considerable proportion of the number of fruits set and Pyke (1932) has shown that, in Trinidad, wilt may account for losses of fruits ranging from 19 to 92.5% of the number of fruits set on different trees. It is highly improbable that it would be possible for a cacao tree to bring to maturity all the pods that are set, but if the wilting percentage could be decreased by 10% considerable increases in yield, acre would result. It is presupposed that the inherent fertility of the soil would be sufficiently high to support such an increase in the crop.

The causes of cherelle wilt have been investigated and there is good evidence that wilt is primarily a physiological disease. Cope (1938) found that applications of potassium fertilisers increased the number of pods which reached maturity, mainly through a reduction in the number of pods which wilted. He concluded that competition for nutrients and water were at least partially responsible for cherelle wilt. Humphries (1943a, 1943b, 1944 and 1947), in a series of detailed papers, came to a similar conclusion, producing a good deal of evidence to support this view. However, the mineral injection experiments of Murray (1952), in which mineral solutions at non-toxic concentrations were injected into the trees, did not show a reduction in the percentage of pods lost by wilting. Bartolomé (1951), working in Costa Rica, was similarly unable to reduce wilting by application of fertilisers, although he points out that the inherent fertility of the soil is high in the region in which the experiments were conducted.

Recently, the relationship between natural growth-hormones (or auxins) and fruit-drop has been investigated, e.g. Luckwill (1953), Nitsch (1952) and Wright (1956). Briefly, the hypothesis as applied to temperate fruit-drop, such as the apple, is that abscission of the young fruits is highest when the auxin production of the seeds is lowest. The reduced production of auxin ultimately results in the formation of an abscission layer responsible for the shedding of the fruits. McKelvie (1956) has produced evidence to suggest that wilt in cacao is related to fruit development and hence by analogy to other crops is probably related to the inherent hormone production of the developing pods. The hypothesis that wilt of young

cacao fruits may be a physiological thinning mechanism, analogous to fruit-drop, may be adopted with certain reservations. It must be borne in mind that the hormonal control of wilt, if in fact such is the case, will be expressed probably through the medium of vascular differentiation and will not involve an inhibition of the development of an abscission layer. McKelvie (1956) is of similar view.

Fruit-drop in certain temperate fruits, e.g. the apple, may be controlled by synthetic growth substances and experiments have been conducted on cacao to control wilt in a similar fashion. Naundorf and Villamil (1950) claimed a reduction in wilt using beta-naphthoxy acetic acid (NoXA) and alpha-naphthalene acetic acid (NAA), and Gardner and Naundorf (1950) found a reduction in wilt using chlorophenoxy acetic acid or NAA. However, Murray (1952), using NAA, NoXA, 2 : 4 dichlorophenoxy acetic acid (2 : 4D), 2 : 4 dichlorophenoxy propionic acid (2 : 4DP) and 2 : 4 : 5 trichlorophenoxy acetic acid (2 : 4 : 5T), was unable to repeat the results obtained by Naundorf and his co-workers on cherelle wilt. He was able to show, in agreement with Naundorf, that NAA and 2 : 4 : 5T were able to improve flower setting by prolonging the period over which flowers remained receptive to pollen. McKelvie (1954), using NAA and 2 : 4D, was also unable to repeat the results obtained by Naundorf.

The reasons for the lack of agreement may be several, but the lack of an abscission layer in cacao fruits and the irregular nature of the fruit setting suggest that control by synthetic compounds may well be difficult. It is of interest to note at this stage that, where a true abscission layer is found in cacao, control can be exerted by synthetic growth substances, e.g. Murray (1952) on flower retention. Nichols and Akinbode (1956), using the petiole abscission method of Edgerton (1947) with a view to screening certain growth regulators for wilt-control and leaf-drop control experiments in the field, adapted the method for use with cacao. Edgerton and Hoffman (1953) found that those growth substances which most effectively delayed the abscission of petioles from delaminated apple leaves, were also the most effective in controlling fruit drop. On cacao, 2 : 4 : 5T and 2 : 4D were found to be significantly more effective in delaying petiole abscission, as compared with water treated controls. In the case of petiole abscission, a definite abscission layer is involved.

With the conflicting results of the effect of synthetic growth substances in mind, it seemed desirable to investigate the natural growth substances of cacao in relation to fruit development and this paper records the preliminary results of this work.

Cherelle wilt is also thought to be intimately connected with "flushing" (the rapid growth of terminal buds of

fan branches), competition for nutrients between young pods and expanding flushes resulting in the starvation of the developing fruits. With this possible relationship in mind investigations of the growth substances in buds and expanding flushes were carried out.

The acidic growth substances of seedlings have also been investigated.

Experimental methods

The technique of extraction of the growth substances was essentially that of Bennet-Clark and Kefford (1953) with minor modifications. Most of the work reported has been carried out on alcoholic extracts of fresh tissues. A known fresh weight of the tissue was rapidly frozen and left overnight in the freezing compartment of a refrigerator. The following day, the tissue was macerated in a minimum volume of redistilled rum spirit (approximately 95-98% ethyl alcohol) and allowed to stand for 24 hours at 5°C. The alcoholic extract was then filtered from the solid residue and the alcohol distilled off under reduced pressure, to leave an aqueous residue. The aqueous residue was adjusted to pH 3 with approximately N hydrochloric acid. The residue was then extracted with peroxide-free ether in a constant extractor of the "liquid by a lighter solvent" type. The ether extract was shaken with sodium bicarbonate solution, the acidic and alkaline substances passing into the aqueous layer, the neutral substances remaining in the ether. The bicarbonate solution was acidified to pH 3 with hydrochloric acid using methyl orange* as an indicator and the acidified solution was further extracted with ether (Larsen 1955). This ether extract then contains the acidic substances.

Only the ether extracts containing the acidic and the neutral fractions have been used in this work.

The extracts were further separated by the technique of paper chromatography and growth-active areas detected on chromatograms by either an oat or wheat coleoptile straight growth test.

The ether extracts were concentrated to a small volume *in vacuo* and loaded on to Whatman's No. 1 filter paper by means of an "Agl" micrometer syringe.

Isopropyl alcohol : water : ammonia (10 : 1 : 1) was used as the developing solvent in the experiments reported here. IAA was used as a marker, separated from the plant extract by a strip of the filter paper cut-out lengthwise down the chromatogram and extending behind the point of application of the extract. This procedure was very necessary to ensure that there was no lateral spread of the synthetic IAA into the plant extract. A control strip of paper was also run in the same solvent. IAA was found to have an Rf value of between 0.32 and 0.42. Rf value may be defined as the ratio of the distance run by the substance under investigation, to that distance travelled by the solvent front. Chromatograms were run in darkness to a length of between 20 and 30 cm., dried in darkness and

* Care must be exercised with the use of methyl orange as an indicator. It was found that occasionally a little methyl orange was carried over into the ether layer containing acidic substances in the emulsion formed between the two solvents. Whereas the methyl orange is masked by pigments at the start line of the chromatogram in the alkaline isopropanol solvent, after development and spraying by the acidic sprays used for detection of indole compounds, the methyl orange gives a red coloration close to the Rf for IAA.

examined under U.V. light. A strip of the chromatogram paper, 2 cm. wide, including the point of application of the plant extract was cut out and divided into 10, 15 or 20 equal segments. Each segment was then immersed in M/100 phosphate buffer containing ten 3-mm. long coleoptile sections and shaken for 23 hours. Forty control sections were similarly treated using segments of paper from the control strip. At the conclusion of the experiment the coleoptiles were transferred to a glass plate in a little of the phosphate buffer and photographed.

The negative was later projected and the coleoptile images could be readily measured. Results are expressed as the percentage extension of the original length of the coleoptiles plotted against the chromatogram segment number. The first segment includes the point of application of the extract, the last segment includes the solvent front. The position of the IAA marker is shown as a short, labelled horizontal bar.

The horizontal line running across the histograms represents the mean length of 40 control sections and the two lines on the vertical scale, on either side of the control line, represent the fiducial limits at the 5% level estimated from the variation between the means of 4 sets of 10 control sections from 10 experiments.

Only experiments which have been consistently repeated have been included in the results section.

Results

With a view to investigating the commonly observed feature of leaf-drop in the field, extracts were made of leaf flushes in all stages of development, from the breaking of the buds to the maturation of the mature flush.

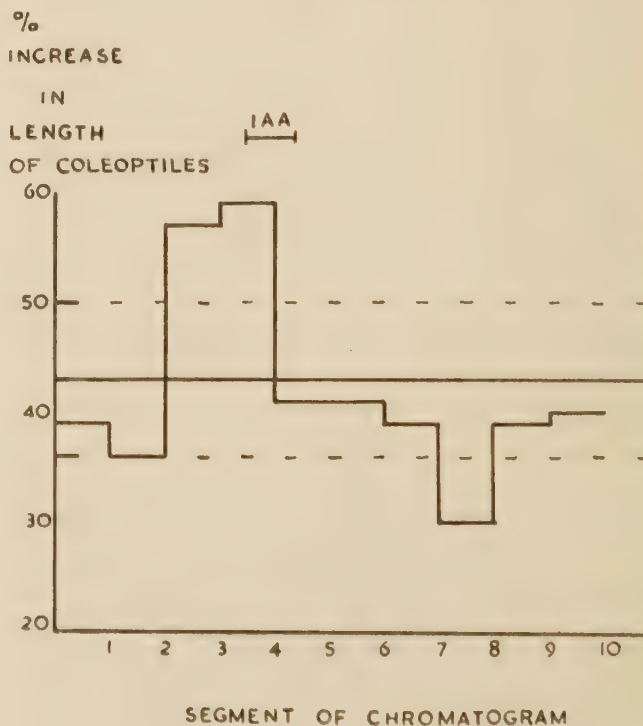


FIGURE 1

Acidic fraction of young flushes, 50 gm. fresh weight; selected approximately one week from bud break.

Leaves

Leaves from ICS 1 were used in these experiments. Fig. 1 illustrates the growth-active areas from 50 gm. fresh weight of young, red flushes approximately one week from bud break and 10 cm. in length, measured from the base of the bud scales to the tip of the expanding flush. Two growth zones are apparent, an acidic accelerator at Rf 0.4 (Segment 4) and an inhibitor at Rf 0.7. The extension growth seen in segments at Rf 0.5-0.6 is the net effect of some of the extension due to the accelerator being modified by the inhibitor. On longer chromatograms the inhibitor clearly shows up at Rf 0.6-0.7.

The accelerator corresponds to the Rf value for β Indolyl acetic acid but evidence will be presented later

that this growth substance from the extract may not be IAA, although it is probably a related compound.

Flushes from a later stage of development, when the leaves have reached almost mature size, having lost most of the red anthocyanin pigmentation but without the characteristic brittleness of the cuticle of the mature leaves, show a similar result to the young red flushes, two growth substances, an accelerator and an inhibitor.

Extracts from mature leaves—Fig. 2—selected well down the branch, which have reached the physiological age at which abscission is common, do not show the acidic accelerator but only the presence of an inhibitor of similar Rf characteristics to the inhibitor present in the young flushes.

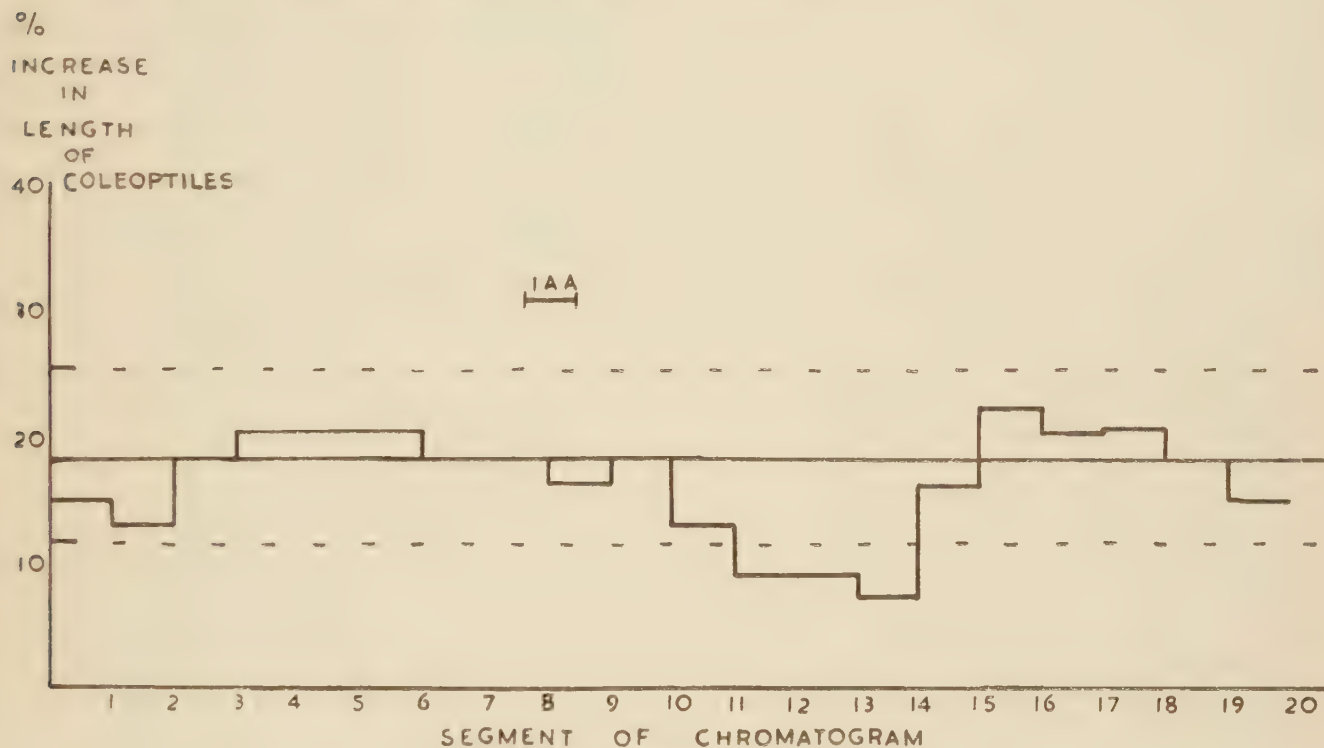


FIGURE 2

Acidic fraction of mature leaves; 50 gm. fresh weight.

The acidic accelerator apparently disappears between the hardening stage of the flushes and the maturation of the leaves and is associated with growing tissues or tissues undergoing differentiation.

Hancock and Barlow (1952) tracing the change in hormone content of leaves from apple shoots, similarly found a progressive decrease in an acid accelerator at Rf 0.3, selecting leaves from the tip backwards towards the mature leaves.

Seedlings

Alcoholic extracts of seedlings have been examined for growth substances essentially to observe if there is any hormone difference between seedlings and tissues derived from fan branches, which may account for the dimorphism of cacao trees. No studies were made of tissues immediately before and after development of the seedling jorquette.

Figs. 3 and 4 are histograms of extracts from 212 eleven-week-old seedlings, separated into apical buds and internodes respectively. The buds include the bud scales. The internodes were taken between the first and second pairs of expanded leaves.

The seedling extracts show very clearly the accelerator at Rf 0.4 corresponding to the IAA marker but the inhibitor is apparently absent. In bio-assays of the seedling leaves the acidic inhibitor is clearly present whereas the accelerator is absent.

As the seedlings appeared to be a good source of the acid accelerator, numerous attempts were made to identify this substance as IAA by spraying with ferric chloride/perchloric acid or the p-dimethyl amino benzaldehyde reagent, both of which give a pink colouration with IAA; with neither spray was any colour developed in the IAA region of the chromatograms. Colour development may have been masked by pigments carried over in the ether

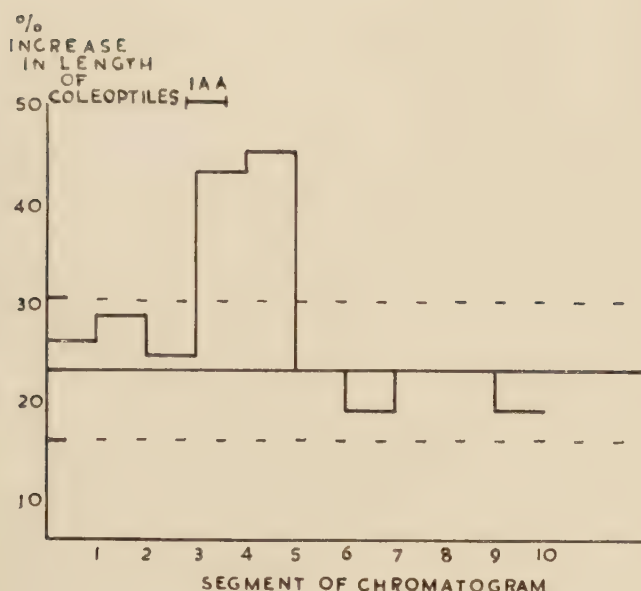


FIGURE 3

Acidic fraction of terminal buds from 212 seedlings; 8.1 gm. fresh weight.

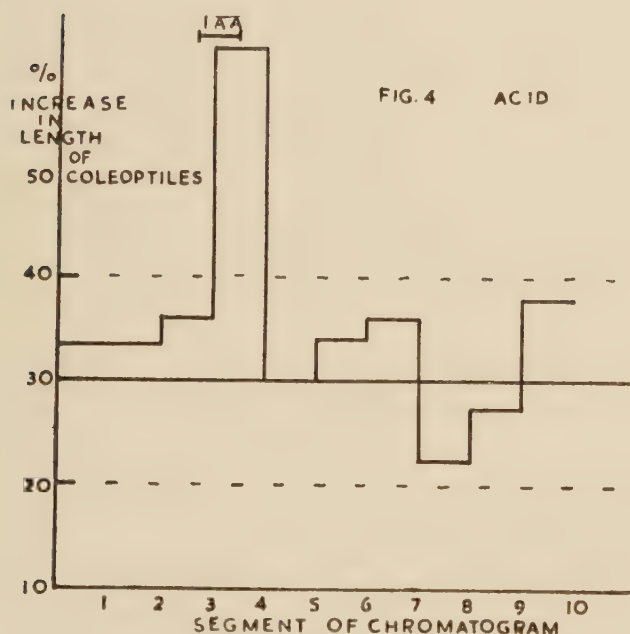


FIGURE 4

Acidic fraction of internodes from 212 seedlings; 10 gm. fresh weight.

extract and, in order partially to obviate this, extracts of etiolated seedlings were run on chromatograms and sprayed, but no positive results were obtained. It is now thought that this substance is not IAA.

Pods

The acidic and neutral growth substances in pods at progressive stages in development to the mature fruit have been investigated qualitatively. Three growth

substances have been consistently recognised in the pods, an acidic accelerator and an inhibitor, similar in nature to those substances found in the tissues previously reported, and an accelerator from the neutral fraction having an Rf value of 0.7-0.8 in the isopropanol developing solvent.

Previous workers (Humphries 1943) have shown that pods rarely suffer from physiological wilt having once reached a critical size in development, usually some 70 days after fertilisation, corresponding to an approximate pod length of 10-11 cm. It was therefore thought desirable to extract the ovules from pods of different physiological ages using length of pod as a rough criterion of age in order to see whether "past-wilting" or mature pods differed essentially from young pods in their growth substance content, bearing in mind that a large proportion of pods from the latter class will in fact never reach maturity, if allowed to remain on the tree. Most of the work reported was carried out in the middle of the wet season, when the main crop is developing, a time when the percentage wilting of the young pods is at its highest.

The early experiments were conducted using alcoholic extracts of 25-50 gm. F.W. of ovules from the pods under investigation. In the smaller pods, the pod-wall was pared off to the surface of the ovules; in the older pods the pod-wall readily separates.

The fresh weights include the central core of pith. The limitation of the use of fresh weight as a basis for comparison is realised but as this investigation is essentially qualitative some comparison of hormone activity from ovules of different ages may be obtained.

Figs. 5 and 6 illustrate the acidic growth substances detected from 25 gm. F.W. of ovules from pods 3 cm. and 14 cm. long, respectively. The acidic accelerator is apparently absent in the younger pods but clearly present in the older pods. Fig. 7 shows an extract of 50 gm. F.W. of ovules from pods 4 cm. long run on a shorter chromatogram, illustrating the activity of the inhibitor in segment 6 which almost completely suppresses the normal extension of the coleoptiles. In segment 3 the acidic accelerator is present but in very low concentration.

Further work suggested that activity of growth substances in low concentration might be more clearly shown up if larger quantities of tissues were extracted and 500 gm. F.W. was chosen arbitrarily. Fig. 8 shows the growth substances from 500 gm. F.W. of pods 3-4 cm. long. The active zone in segment 14 is not an acidic accelerator but a growth substance from the neutral fraction which passes over during the bicarbonate partition. This observation was of particular interest as indolyl acetonitrile behaves in a similar fashion (Bennet-Clark and Kefford 1953).

Figs. 9 and 10 are bio-assays from acid and neutral fractions of 500 gm. F.W. of ovules from pods 5-6 cm. in length corresponding to a post-fertilisation age of 46 days (data from Humphries (1943b)). The acidic accelerator is clearly present in segments 4, 5 and 6 and the inhibitor in 8, 9 and 10. The accelerator in segments 11 and 12 is a spill-over from the neutral fractions as in Fig. 8 and may be clearly seen in the neutral fraction of Fig. 10. The activity of the acid inhibitor is very high, in spite of a partial masking by some of the neutral substance in the acid fraction.

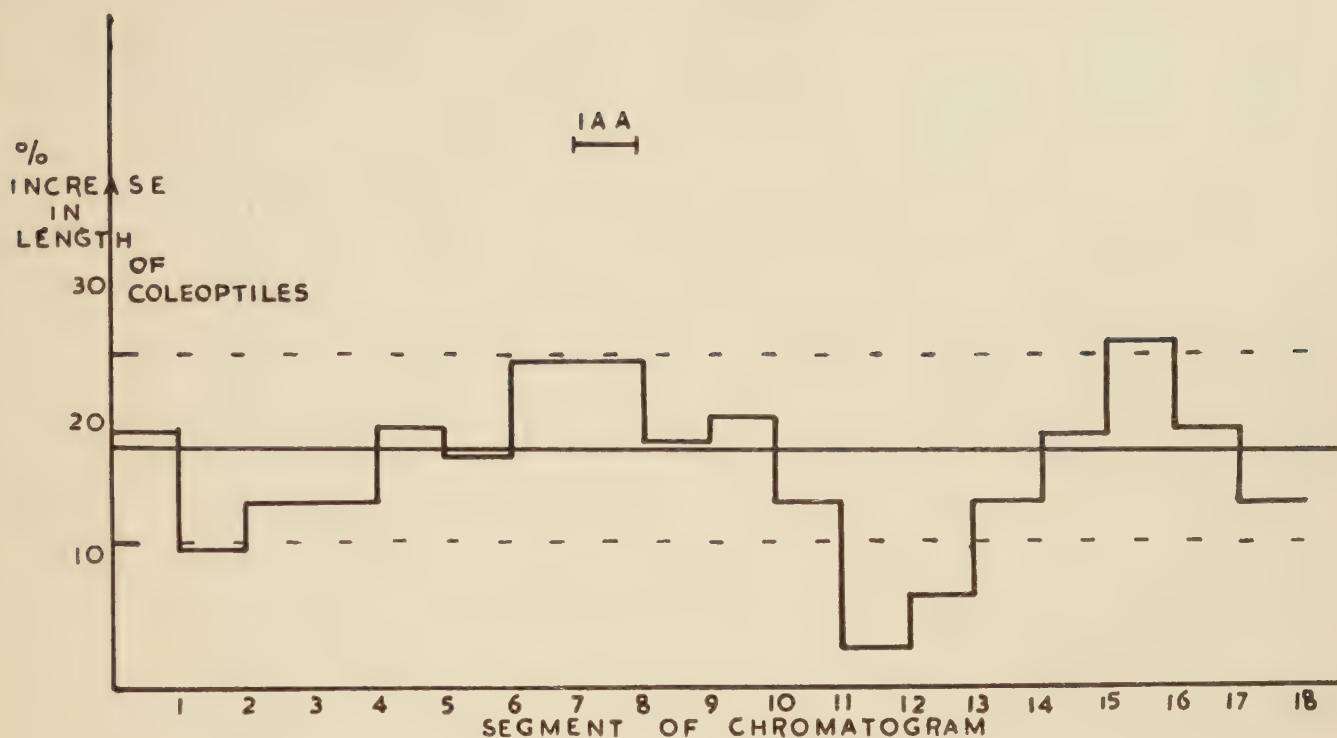


FIGURE 5
Acidic fraction of ovules from pods 3 cm. in length. Fresh weight of ovules, 25 gm.

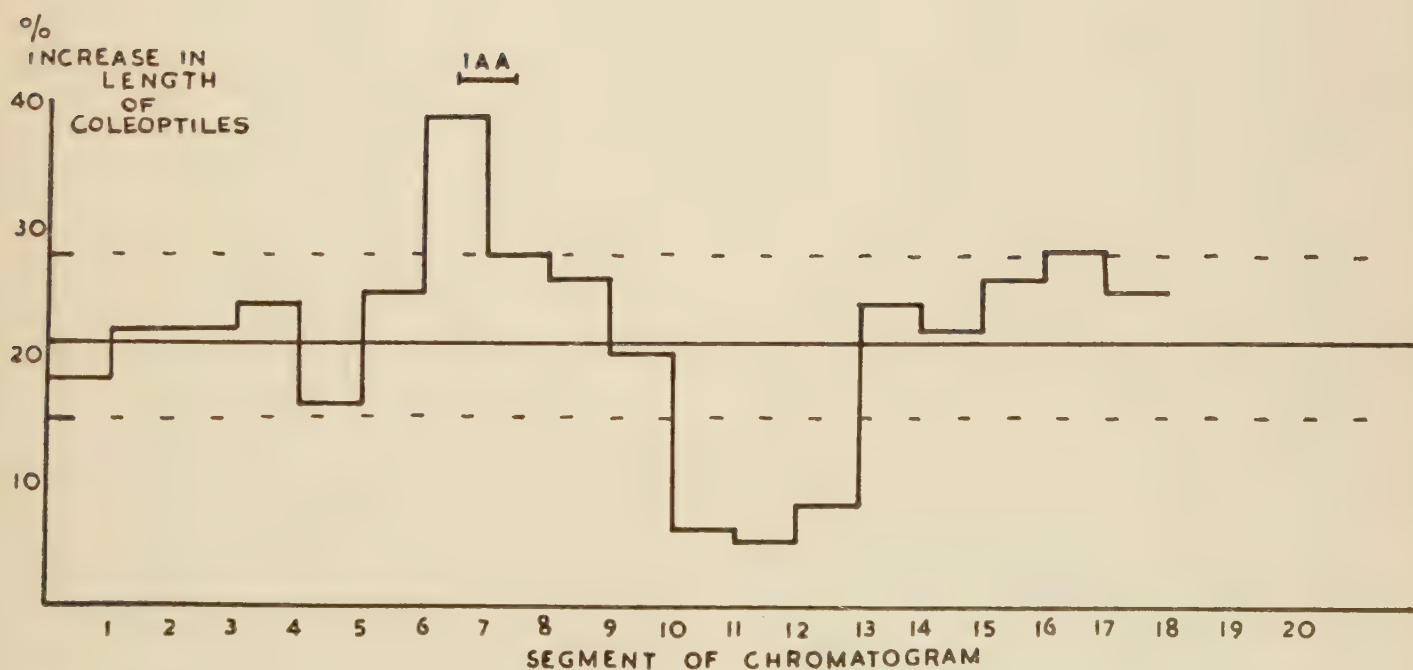


FIGURE 6
Acidic fraction of ovules from pods 14 cm. in length. Fresh weight of ovules, 25 gm.

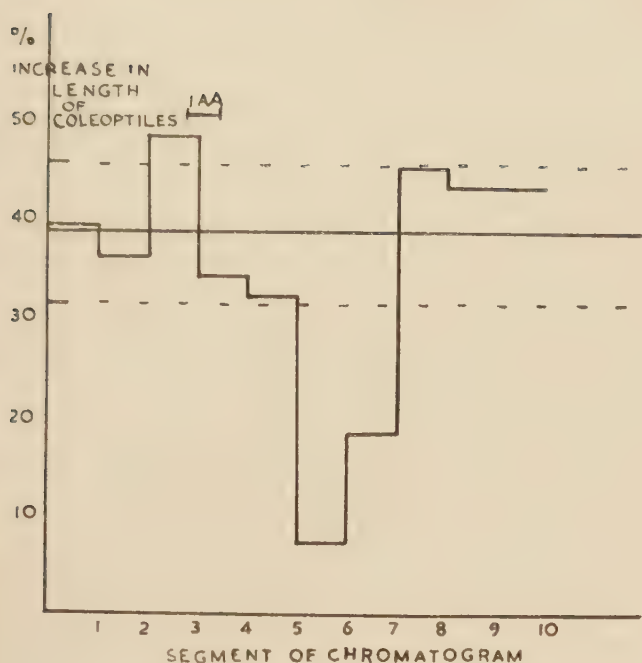


FIGURE 7

Acidic fraction of ovules from pods 4 cm. in length. Fresh weight of ovules, 50 gm.

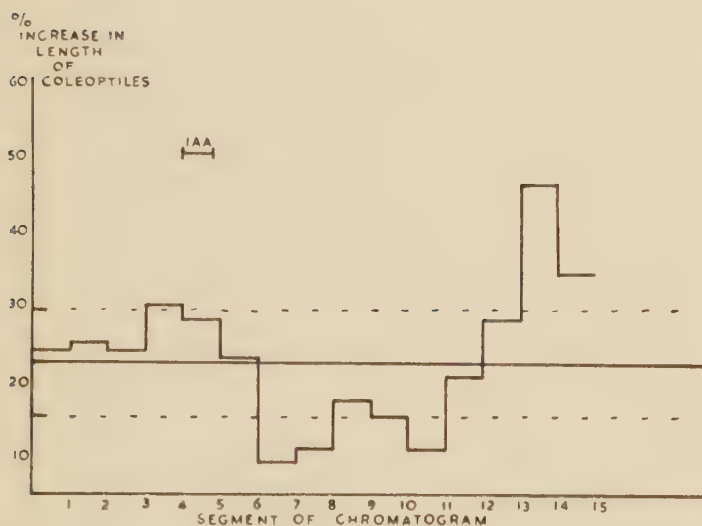


FIGURE 8

Acidic fraction of ovules from pods 3-4 cm. in length. Fresh weight of ovules, 500 gm.

Figs. 11 and 12 are bio-assays of ovule extracts from pods 11-13 cm. in length, approximately 70-80 days after fertilisation, at a stage when physiological wilt is unlikely to occur. The inhibitor is still present in the acid fraction but the neutral growth accelerator has built up to a relatively high concentration, equivalent to an IAA activity of 10 p.p.m. at the peak of its highest activity in segment 10.

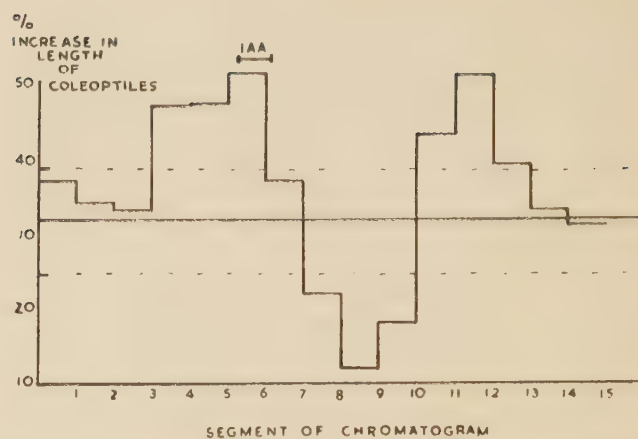


FIGURE 9

Acidic fraction of ovules from pods 5-6 cm. in length. Fresh weight of ovules, 500 gm.

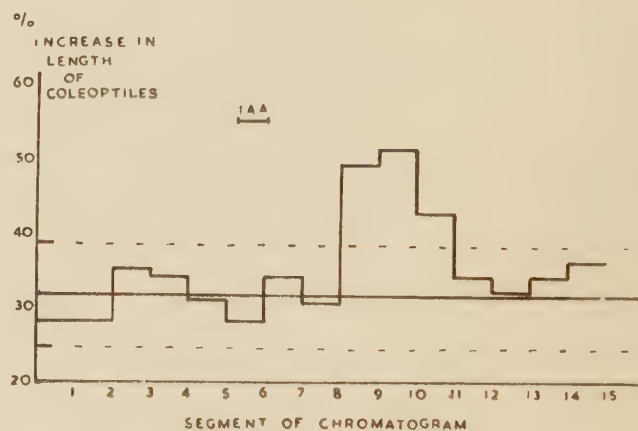


FIGURE 10

Neutral fraction of ovules from pods 5-6 cm. in length. Fresh weight of ovules, 500 gm.

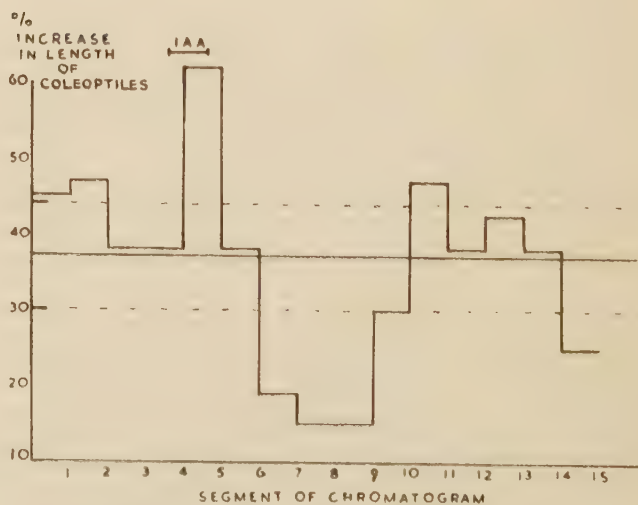


FIGURE 11

Acidic fraction of ovules from pods 11-13 cm. in length. Fresh weight of ovules, 500 gm.

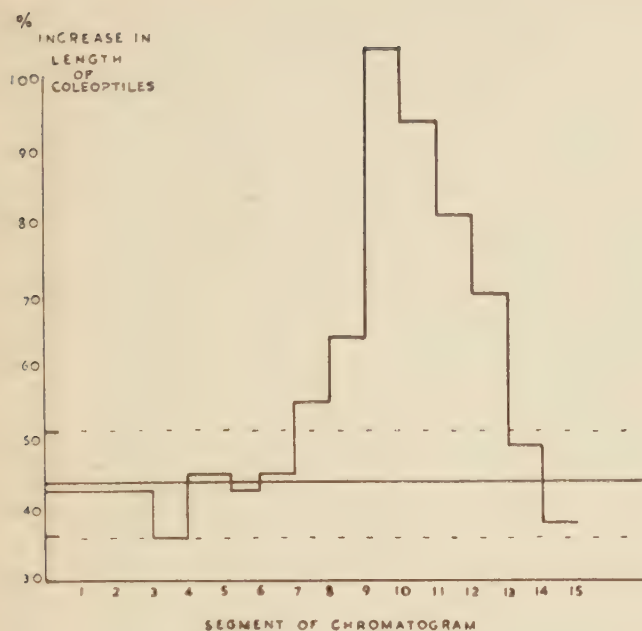


FIGURE 12

Neutral fraction of ovules from pods 11-13 cm. in length. Fresh weight of ovules, 500 gm.

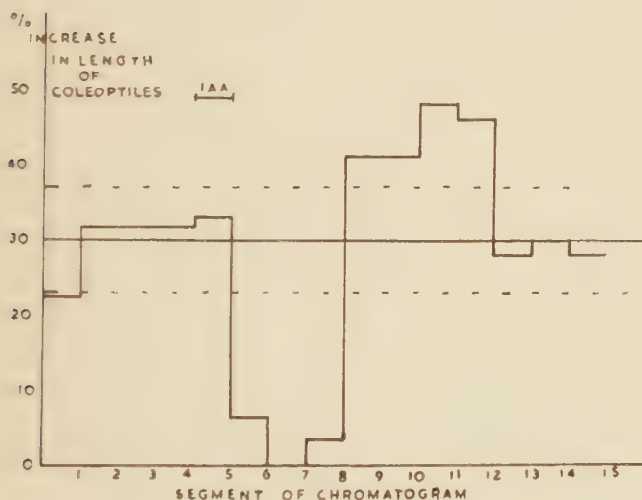


FIGURE 13

Acidic fraction of mature fruit stalks. Fresh weight of stalks, 198 gm.

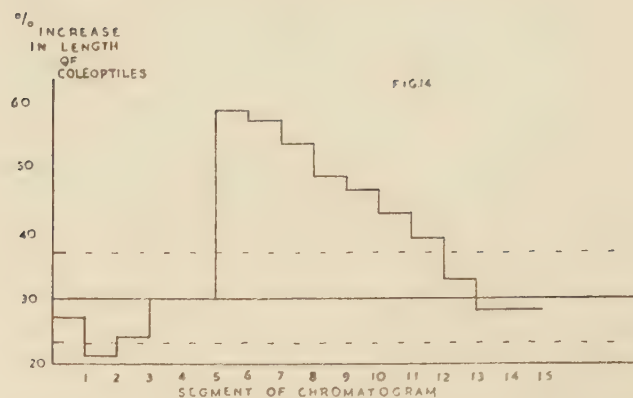


FIGURE 14

Neutral fraction of mature fruit stalks. Fresh weight of stalks, 198 gm.

Fruit stalks

Extracts from mature fruit stalks have been examined to observe if the growth substances of the ovules are found in the vascular system. The results are plotted in Figs. 13 and 14. The activity of the acid inhibitor in segment 7 is of interest. It may be noted that the neutral accelerator and acid inhibitor are both present but the acid accelerator is apparently absent.

Numerous attempts have been made to identify the two accelerators by chemical sprays and developing the extracts in different solvents, but without success. The neutral accelerator, if it were IAN, after alkaline hydrolysis should give growth activity in the IAA position (Bennet-Clark private communication); however, the neutral accelerator reported here, after hydrolysis, maintains the activity at its original Rf value. This is strong presumptive evidence that it is not IAN, but is very probably a related compound. Further work is required on the acid accelerator, although the present work suggests that it is not IAA, in spite of its activity in the IAA position on the chromatogram. Luckwill (1956) has recently reported the absence of IAA in the apple, a tissue which hitherto had been assumed to contain IAA by virtue of the presence of an acid accelerator, running at an Rf similar to IAA (Hancock and Barlow 1952).

Discussion

For the sake of clarity in discussion, it is proposed to call the acid growth accelerator similar in behaviour to IAA, Cacao auxin I (auxin I) and the neutral accelerator referred to in the text, Cacao auxin II (auxin II).

The interesting observation from the work on extraction of developing ovules is the appearance of auxin I which reaches a peak some 70-80 days after fertilisation. Auxin I maintains a similar level of growth activity until the ovules reach maturity. It is tempting therefore to suggest that auxin I is associated with wilt control for it accumulates approximately at the stage in development of the ovules after which fruits are unlikely to be lost by physiological wilting. A similar relationship between fruit-drop and hormone production has been shown to exist in temperate fruits, e.g. the apple. However, at this stage in development, 70-80 days after fertilisation, rapid growth of the embryo is taking place at the expense of the endosperm. Growth of the embryo continues to take place until just before ripening of the pod. In temperate fruits, the

The zone of growth activity in segments 1 and 2 of Fig. 11 has not been found consistently in cacao tissue and there appears no justification at present in relating the substance responsible for this zone of activity with the alpha-accelerator of Bennet-Clark and Kefford (1953).

Extracts of older pods give an essentially similar bioassay to that recorded for the 11-13 cm. pods, the activity of the acid accelerator remaining at a similar order of activity. The high activity of the neutral accelerator has not been found in these pods, although all three growth substances are present.

endosperm is thought to be the site of hormone synthesis and fruit-drop is associated with changes in hormone content produced in the endosperm. As the embryo develops at the expense of the endosperm the amount of hormone produced by the endosperm is reduced and fruit-drop may take place. Hence in cacao, if the hypothesis be accepted that cherelle wilt is a physiological thinning mechanism comparable to fruit-drop, then wilt may be expected to take place after the 80-day stage when the embryo is actively growing. However, this is not normally observed to take place under field conditions. As shown in this work, at a time when wilt might be expected on the basis of embryo development, auxin I is produced in large amounts from the ovules and physiological wilting does not take place. The relationship between wilt and auxin I is apparent, but the relationship between wilt and the later stages of embryo development is not.

At approximately 46 days after fertilisation (Fig. 9), auxin I is already present at a similar order of activity to that found 70-80 days after fertilisation; no significant decrease in auxin I activity has been noted between these two times of observation. The accumulation of auxin I 46 days after fertilisation may precede the decrease in wilt incidence between first and second wilt, reported by McKelvie (1956).

A strict comparison with temperate fruits cannot be validly drawn for reasons outlined in the introductory section. It was suggested in that section that the causal mechanism of wilt may be an interference in vascular transport or differentiation and from the evidence presented auxin I may be the growth substance involved. Such an hypothesis embraces the current theories of cherelle wilt in relation to water and nutrient competition.

Auxin II, the neutral growth accelerator, follows a similar pattern to auxin I in the ovules and is apparently more active in the coleoptile extension growth test. However auxin II is more stable than auxin I after the

extraction procedure and valid comparisons of activity are difficult to draw.

More recent work on auxin II has shown it to be present in ether extracts of leaves and further work is in progress to determine its physiological activity in cacao. Preliminary results indicate that it is associated with leaf-fall as well as fruit development.

The acid inhibitor which has been found in all the tissues examined is of interest in that an inhibitor of similar Rf behaviour has been found in many plants other than cacao. A physiological function for this inhibitor has not been postulated but it is tentatively suggested that it may have some bearing on the mechanism of cherelle wilt. The inhibitor is found in the ovules at all stages of development and in the mature fruit stalks and may therefore affect other pods through the vascular system. However, a further expansion of this hypothesis must await identification of the inhibitor, with the emphasis on physiological activity in connection with fruit development.

The evidence presented suggest that cherelle wilt is probably under hormonal control and therefore control by synthetic growth substances should be possible. Studies are being made at present to examine this possibility in the field with particular reference to time of application.

Summary

(1) Three growth substances have been detected in cacao, an acidic accelerator (cacao auxin I) similar in Rf characteristics but not identical to IAA, a neutral accelerator (cacao auxin II) and an acidic inhibitor.

(2) Seedlings, leaves, "flushes" and ovules at various stages of development have been examined for growth substances.

(3) A tentative hypothesis has been suggested for the interrelation of growth substances in the ovules to pod wilting.

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A Comparison of Various Methods of Rooting Cacao Cuttings

by

D. B. Murray and C. J. R. Bridge

VARIOUS techniques for rooting cacao cuttings have been developed in recent years. Figures are available for the average percentage of successful rooting by some of the methods but no direct comparison has so far been made under comparable conditions using similar clonal material under the same climatic environment. Such a comparison has now been made and furthermore, since the rooting of the cutting is only the first stage in the production of a plant for the field, the factors affecting hardening and establishment of the plant in its basket have been taken into consideration. That is, both the rooting efficiency or number of plants rooted per 100 cuttings set, and the production efficiency or number of plants finally established per 100 cuttings set, have been investigated. In addition, since the cost of production of a rooted cutting is of considerable importance where the large-scale production of plants is contemplated an attempt has been made to compare costs for the main methods of propagation.

Methods

This experimental work was carried out with the facilities available at the Imperial College of Tropical Agriculture. Basically three methods of rooting together with, in two of the methods, three systems of hardening have been employed. These were:

Rooting method	Hardening method
Closed bins	Hardening bins 1
	<i>in situ</i> 2
	Humidifier 3
Open spray beds	Hardening bins 4
	<i>in situ</i> 5
	Humidifier 6
Centrifugal humidifier	— 7

Method 1 is the original "Trinidad" method of propagation and this was modified by Burchardt and Jorgenson (1950) to give Method 2. The use of a humidified glasshouse by Evans (1951) for hardening results in Method 3. Open spray beds developed by Bowman (1948) are combined with the same three systems of hardening to give the next three methods. Finally, Method 7 was developed by Murray (1954) where the twin operations of rooting and hardening are carried out in baskets with a core of rooting medium in the humidified glasshouse.

Of these methods, only 1, 2 and 4 have been operated commercially with large numbers of plants the remaining methods not yet having been tried on the same scale. The list is not exhaustive other modifications of technique having been suggested of which the La Reunion method of the Trinidad and Tobago Cocoa Board is the most

important. However the range used is considered to cover adequately the basic modifications likely to affect the physiological and environmental conditions pertaining to rooting.

For the experimental work six clones were used, ICS 1, 39, 40, 60, 89, 95, all of which are proved high yielding clones planted commercially to a greater or lesser extent. The standard methods of collection, preparation and hormone treatment were applied to all cuttings. At each setting 90 cuttings of each clone were used, i.e. 30 for each main rooting treatment and these were divided for the various hardening treatments.

Thirteen settings were made at 2 to 3 week intervals between August, 1955, and April, 1956, to cover the range of conditions between wet season and dry season. Altogether nearly 6,000 cuttings were set but there were occasions when the supply of cuttings from the nurseries did not permit of using the full range of clones.

Results

Rooting methods

Cuttings from the closed bins and spray beds were lifted and examined for rooting at 28 days. Methods 2 and 5 involving hardening *in situ* were lifted at 42 days. In Method 7 where the cuttings are not disturbed in the cored baskets such an examination was obviously not possible.

As mentioned earlier, cuttings were not always available in sufficient numbers to set all clones on every occasion so that statistical analysis has not been possible. Inspection of the results however indicated no obvious trends in seasonal effects and the rather voluminous data are not reproduced. It is however a matter of practical experience that rooting results towards the end of the dry season are poor and it must therefore be pointed out that this particular dry season was wetter than average.

TABLE I
Rooting efficiency

Methods	Clones						Average
	1	39	40	60	89	95	
Closed bins	62	95	73	91	88	85	83
Spray beds	74	96	88	93	88	85	88

In Table I is given the average rooting performance of the six clones in the closed bins and spray beds. Both main methods have given extremely good results only

ICS 1, known to be a slightly more difficult rooter, giving slightly poorer results. Clearly, open spray beds, efficiently operated, can give as high a percentage of rooting as closed bins.

Hardening methods

The rooted cuttings from the closed bins and spray beds were placed in baskets and hardened either in closed bins or in the humidifier for 14 days.

TABLE II
Hardening losses (% cuttings set)

Hardening method	Rooting method		Average
	Closed bins	Spray beds	
Hardening bins ...	1.4	1.8	1.6
Humidifier...	1.0	0.8	1.0

The hardening losses given in Table II are almost negligible and there is nothing to choose between the two methods provided that well rooted cuttings are entered in the first instance. Of the clones, ICS 1 again showed a slightly higher loss at 2.7%.

Establishment losses

After the operations of rooting and hardening were completed, the rooted cuttings in their baskets were removed to a shaded glasshouse. Establishment losses were reckoned as the number of plants that died within 14 days. After this period the plants may be considered well established. Losses of plants occur after this but are due to factors which would operate with equal effect on all plants irrespective of the method of rooting.

TABLE III
Establishment losses (% cuttings set)

Method	Clones						Average
	1	39	40	60	89	95	
1	4	2	3	0	0	1	1.6
2	19	26	13	13	18	9	16.4
3	2	2	4	2	5	4	3.3
4	4	3	5	4	3	4	3.7
5	18	10	13	12	11	20	14.1
6	4	4	2	2	4	5	3.6
7	10	4	4	4	5	11	6.4
	8.6	7.6	6.2	5.4	6.6	7.7	

From Table III it is seen that Methods 2 and 5 which employ hardening *in situ* have shown the highest establishment losses. This is to be expected but the aim with *in situ* hardening is to eliminate the cost of the hardening operation even at the expense of efficiency, a feature to be discussed later.

Production efficiency

The final numbers of plants established by each method are given in Table IV.

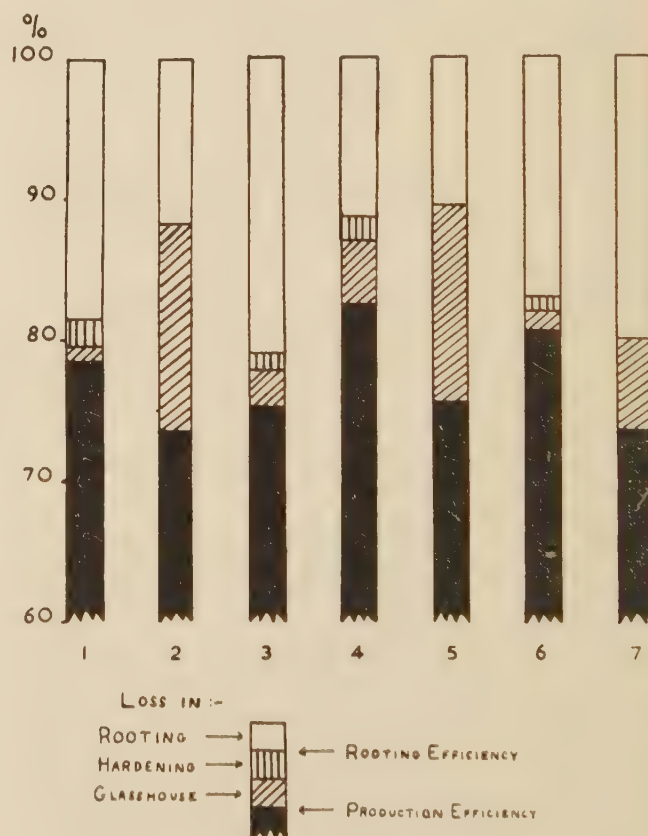
It is clear even without statistical analysis that the production efficiencies of the various methods show only small differences and these are mainly associated with variability of the cutting material. ICS 1 gives slightly

poorer results with all methods but, as mentioned earlier, it is known to be a slightly more difficult rooting clone.

TABLE IV
Production efficiency

Method	Clones						Average
	1	39	40	60	89	95	
1	46	93	74	90	87	82	78
2	60	79	59	80	72	77	73
3	48	93	68	87	80	77	75
4	70	91	83	83	81	78	82
5	62	88	77	81	76	67	76
6	67	85	80	90	81	76	81
7	60	76	77	77	75	60	74
	59	78	77	85	80	75	

The breakdown of the results constitutes Fig. 1. The highest rooting percentage is shown by Methods 2 and 5 due largely to the fact that they have spent 14 days longer in the rooting medium than the plants which were put in baskets at 28 days for hardening. Offsetting this higher rooting however is the greater loss in establishment. Hardening and establishment losses are low in the Methods 1, 3, 4, 6 where a hardening operation is involved. They are not unduly high for Method 7 where the plants are transferred from the saturated atmosphere of the humidifier to normal atmospheric humidity.



These results indicate that, provided the environmental factors for each technique are at their optima and that the operator is experienced and conscientious, consistently

high results can be secured by any of the methods tried. These provisos naturally become more important when large scale propagation involving tens or hundreds of thousands of cuttings per annum is envisaged.

Costs of propagation

Since all the different methods tested are capable of producing a high percentage of established plants the choice of any one method must depend on other factors. The two most important must be the cost of production per plant and the skill and experience of the operators, particularly when propagation is being carried out on a very large scale.

The costing of agricultural operations is not simple, but it was thought desirable to secure at least comparative figures for some of the methods and the results will now be summarised.

The data were obtained mainly from the large propagating stations of the Cocoa Board of Trinidad and Tobago and 4 methods were costed.

- A. Closed bins with hardening bins (Method 1).
- B. La Reunion method. Closed bins with the cuttings set in cored baskets as described with the humidifier method. No hardening bins are necessary the rooted plants being transferred to the glasshouse floor.
- C. Open spray beds, hardening *in situ* (Method 5).
- D. Humidifier (Method 7).

It was not possible to deal with all 7 methods because of limitations of time, labour and equipment.

During the course of the work the following numbers of cuttings were put through each method.

TABLE V

		Method			
		A	B	C	D
Cuttings set	...	2,250	1,500	3,627	3,400
% losses in rooting	...	18	23	30	12
hardening	...	8	—	—	—
establishment	...	4	4	17	7
Production efficiency	...	70	73	53	81

Except for Method C these results agree well with those secured earlier and for the purposes of comparison a uniform production efficiency of 70% is assumed.

Capital expenditure

Full details of the capital costs involved in constructing the various types of propagating equipment would involve very lengthy treatment. Only a summary is therefore given in Table VI, and this excludes such equipment as is common to all methods, i.e. glasshouses, storage sheds, etc.

TABLE VI

Capital cost and annual depreciation per 1,000 plants produced. Cost in B.W.I. \$ (\$1.00 = 4s. 2d.)

Method	...	A	B	C	D
Capital costs	...	420	220	120	470
Annual depreciation	...	49	23	11	32

The most accurate information is for Methods A and B where large numbers of units have been constructed. It is thought that the costs for C and D could be reduced with greater experience in methods of construction. The low capital cost and depreciation of Method C, open spray beds, may be noted.

Labour requirements

In Table VII is given a breakdown of the cost of labour required to produce 1,000 plants by each of the methods. Certain operations, i.e. collection and preparation of cuttings, are common to all methods. The table is self explanatory and shows that the original closed bins, Method A, is considerably more expensive than any of the others. This is due mainly to the costs involved in transferring the rooted cuttings for subsequent hardening and the greater labour requirement for watering during rooting and hardening. A not inconsiderable factor is the cost of washing the cloth covers on the bins which become mildewed very rapidly.

TABLE VII

Labour requirements—cost per 1,000 plants produced. Based on labour rate B.W.I. 35 cents/hour

Methods	...	A	B	C	D
Collection and preparation	...	8.5	8.5	8.5	8.5
Setting	...	1.8	7.6	3.1	10.9
Basket preparation	...	6.9	8.7	6.9	8.7
Hardening	...	38.9	—	—	—
Transfer to glasshouse	...	7.2	6.0	40.4	13.7
Maintenance during propagation	...	84.0	40.8	9.8	8.2
Washing cloth covers	...	22.2	11.1	—	—
Fertilising and cultivation	...	68.7	68.7	68.7	68.7
Watering	...	31.8	31.8	31.8	31.8
Repotting	...	37.0	37.0	37.0	37.0
Total	...	307.0	220.2	206.2	187.2

Costs of Materials

The cost of materials used during propagation constitutes Table VIII. The cost of the cuttings includes all nursery operations and depreciation. A high standard of maintenance is essential for the production of satisfactory material for propagation. The largest item of expenditure, common to all methods, is for baskets, approximately 2½ baskets being required for each plant ready for the field.

TABLE VIII

Materials used during propagation. (Cost per 1,000 plants produced P.E. 70%)

Methods	...	A	B	C	D
Soil, including preparation	...	46.2	54.3	43.4	54.3
Baskets	...	150.0	150.0	150.0	150.0
Fibre	...	4.8	—	8.2	—
Cloth (bin covers)	...	28.0	16.8	—	—
Hormone	...	2.5	2.5	2.5	2.5
Cuttings	...	40.8	40.8	40.8	40.8
Total	...	272.3	264.4	244.9	247.6

Water consumption

This is often a factor of considerable practical importance, Method C involving the highest consumption and D the least.

TABLE IX

Water consumption and costs at 60 cents per 1,000 gallons

Method	A	B	C	D
Gallons water per day ...	720	400	2,800	100
Cost per 1,000 plants ...	19	12	104	4

In Table X is given the final summary of costs of production excluding general overheads and also transport of soil and other materials.

TABLE X

Summary of costs per 1,000 plants produced (P.E. 70%) excluding general overheads

Method	1	2	3	4
Annual depreciation—				
Propagators	48.7	22.7	11.2	31.7
Glasshouse	10.4	10.4	10.4	10.4
Storage shed... ..	54.2	54.2	54.2	54.2
Water	19.4	12.0	103.7	4.0
Electricity	—	—	—	.6
Labour	307.0	220.0	206.2	187.2
Materials	272.3	264.4	244.9	247.6
	712.0	583.7	630.6	535.7

The cost of production by the cheapest methods shows a saving of 25% on the most expensive method and such a saving would be appreciable when propagation is conducted on a large scale. All methods are cheaper than the oldest closed bins system, but these can fairly easily be converted to the La Reunion method using cored baskets.

Although it has been shown that with efficient labour and supervision there is little difference in the final results with any of the methods, on a very large scale losses may be much higher and particularly so in methods when the root system is exposed. Very often inadequately rooted plants are placed in the baskets and result in high losses at later stages. The advantage of systems such as the humidifier and La Reunion methods using cored baskets and a saturated atmosphere stems mainly from this factor.

The use of open spray beds is largely dependent on water supply. If adequate water is available at little or no cost the figure for cost of water in Table X could be

subtracted, making this method the cheapest of all. On a large scale it is difficult to reproduce a consistently high degree of rooting but spray beds are recommended to cope with periods of the year when cuttings are available in large numbers. One of the problems of propagation lies in the fact that the production of cuttings from the nursery varies with season and the low capital cost of open spray beds permits of their being operated only at periods when more cuttings are available than can be accommodated in the closed bins.

In using the humidified glasshouse method, some difficulties have been experienced with light control, light starvation of the plants in certain parts of the house occurring in dull cloudy weather. This has now largely been overcome by the use of adjustable aluminium strip shutters placed on the roof. These are fully opened in the morning and afternoon or in dull weather and are closed to varying extents during the middle of the day.

The results of this work have shown that a fairly wide range of propagating techniques are all capable of producing a high percentage of rooted cacao plants when operated under optimum conditions. There is obviously no single best system for cacao propagation and the choice of a method or methods must depend on a range of factors, some of which have been discussed. The breakdown of the cost of production shows the main differences between the various systems and also gives an idea of the relative importance of the different costs. It must be appreciated that these costs hold for large propagating stations of a semi-permanent nature and that on a small scale economies in such features as glasshouses and standing floors may be effected.

Summary

1. A comparison has been made of seven different techniques for rooting and establishing cacao cuttings. All methods are capable of giving comparable figures of 75-80% established plants provided that they are operated efficiently.

2. A breakdown of the cost of production of four methods has been prepared and it is shown that savings of up to 25% may be effected on the most expensive system.

Acknowledgments

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Shade Trees for Cacao

by
D. B. Murray

THE use of a planted shade tree for cacao is traditional in Trinidad and many of the older cacao-growing countries. In West Africa tree shade is seldom if ever planted, a few of the forest trees being left when the land is cleared to provide a certain degree of shade. The association of shade trees with cacao is known from some of the earliest historic records, Bontekoe in his treatise on cacao written in 1679 illustrating a *cacautl* tree with a shade tree conveniently leaning over to provide the maximum protection of the cacao tree from the burning rays of the sun.

Experimental work in recent years (Murray 1954, Havord *et alia* 1955) has led to a considerable increase in knowledge of the function of shade in cacao. Using artificial shade to reduce the complicating factors of root competition, etc., it has been shown that shade exerts a buffering effect on the tree when grown under sub-optimum conditions. On fertile soils cacao can be grown without shade and gives high yields, but when environmental factors, in particular the supply of mineral nutrients, depart from the optimum shade trees are necessary or the cocoa will not make healthy growth and yields will suffer.

Field support for this contention was given some 15 years ago when attempts were made in Trinidad to grow clonal cuttings without shade on certain estates. Even though spaced more closely than normal to simulate the Grenada system the trees rapidly developed symptoms of mineral deficiencies and made very disappointing growth. We now know that this failure was due to poor nutrient supply on the heavy Trinidad soils. Apart from its role in controlling the mineral status of the cacao tree, the shade tree acts as a windbreak and may also modify the soil moisture relationships, particularly in countries with a pronounced dry season. The importance of windbreaks is derived mainly from personal observations, though Hart (1911) does quote figures from Ceylon where, with wind belt trees, a yield of some 14,000 pods per acre was given over a three-year period as against only 8,000 without wind belt trees. As regards soil moisture little experimental data exist but in some areas the shade trees are considered to compete with the cacao in the dry season to the detriment of the cacao whereas in other areas the experience is the reverse. The problem is a complicated one and must involve the nature of the soil and the habit of the shade tree, whether it is deep or shallow rooting, whether it drops its leaves in the dry season and whether this reduction of transpiring area compensates for the increased water loss of unshaded soil and cacao.

Shade trees must therefore be considered a necessary evil where environmental conditions are not such as to permit the culture of the crop without shade.

The actual shade trees grown differ in various countries but perhaps those most commonly employed are the various species of *Erythrina*, the Immortelle of Trinidad and the Dadap of the East. Little information exists on the reasons for the predominance of the Immortelle but it is presumed to have been selected in the distant past by trial and error as a suitable shade. Neither the Bocare (*Erythrina glauca* Willd.) nor the Anauca (*Erythrina poeppigiana* Walp. O. F. Cook) is indigenous to Trinidad, the former being a native of Venezuela and the latter of Peru. That their introduction was made indicates that considerable value must have been attached to them.

Some twenty years ago, a fungus disease, *Calostilbe striispora*, was found to be causing the death of many Immortelles, particularly old Bocares growing in wet areas in Trinidad. To try to find other tree species that would be unaffected by the fungus Thorold (1945) planted 15 species for observation as possible new shade trees for cacao. More recently a new and as yet undetermined disease, Immortelle Witches' Broom, has decimated the Anaucas in the Montserrat district of Trinidad and has shown the urgency for new and alternative shade trees.

At five years from planting Thorold found none of the trees had developed any disease symptoms and suggested three, *Peltophorum ferrugineum*, *Schizolobium excelsum* and *Parkia roxburghii*, as worthy of further trial as shade trees. Later observations by de Verteuil (1955) indicated only the first of these as worthy of further trial, none of the species being as suitable as *Erythrina glauca*.

Starting in 1952 a further range of species has been planted at River Estate including many new introductions. The desirable features of a shade tree are not easy to evaluate, the acid test being the growth and cropping of the cacao that it shades. With over 30 species under trial a statistical trial would involve far too great an area of land and only single plots of approximately one-fifth acre have been established. The trees are spaced at 24 ft. $\times$ 24 ft. and cacao has been established at 12 ft. $\times$ 12 ft. Bananas are interplanted for temporary shade.

Some of the features that are of obvious importance in a shade tree are ease of establishment, freedom from diseases and pests, resistance to wind both of the tree and of the branches, period of leaf fall in relation to dry season, etc. Minor points are the absence of thorns to permit pruning and a smooth bark that does not harbour epiphytes. Other factors are not so easy to evaluate; thus rapid growth in its early years is an advantage to produce shade quickly, but a tree that grows to an enormous size is not desirable. The cacao tree tolerates more and more light as it grows in

size and self-shading becomes important so that an over-dense shade canopy in later years is undesirable. Shade tree spacing will enter the picture but it is considered preferable to have trees with a light canopy where more light is required and trees with a heavy canopy for less suitable conditions. Attempts have been made in some countries to use other economic trees as shade such as rubber, oil palm and the coconut. Seldom, however, can the optimum requirements of both crops be met at the same time.

As regards the arguments for and against leguminous trees, a trial is already in existence at River Estate (Havord *et alia* 1954) to shed light on this factor, but results are not yet available.

A list of the trees under trial is given in Appendix I and short notes on the performance of the earlier planted ones follow. Unless otherwise stated all are members of the Leguminosae.

Adenanthera pavonina (Jumbie bead). This tree, a native of Asia, established poorly and has made slow growth. Williams (1941) states that it is grown as a shade for plantation crops in Malaya but it seems to have little future under Trinidad conditions.

Albizia lebbek (Woman's tongue). Originally introduced from the East Indies. Not easy to establish. Makes fairly fast growth but does not give much spread of canopy which tends to be rather dense. Has been used for shade in Madagascar where it was kept under control by pruning.

Azadiracta sp. (Neem). One of the few non leguminosae under trial. Growth has been very poor and this species may be discarded as a possible shade tree.

Caesalpinia coriaria (Divi-divi). Rather small tree with light feathery foliage. Too small to warrant consideration as a shade tree.

Cassia multijuga. This Cassia is rather slow growing and straggling but gives a light open canopy. Does not develop into a large tree.

Cassia reticulata (Wild senna). An extremely fast growing small spreading tree which gives a good shade very quickly. Has been tried as a shade tree in recent years both in Trinidad and Grenada but is very short lived, collar rots tending to develop at 5-7 years of age, which lead to the early death of the tree. It does, however, establish well under rather poor conditions and merits use as a temporary shade. It has been stated that cocoa grown under this tree is retarded and there is some sign of this in the present planting.

Enterolobium cyclocarpum (Devil's ear). A rapid growing tree which can make an immense widely spreading tree. Foliage is light and feathery and when young constitutes a good light shade. Being non-thorny it would be possible to control growth to some extent by periodic lopping of branches or ring barking.

Erythrina glauca (Bocare immortelle). The standard Trinidad shade tree for low lying wet areas. Rather slow early growth eventually making a tall tree with heavy canopy. Liable to drop its branches when old resulting in considerable damage to the cacao trees.

Erythrina Poepigiana (Anauca immortelle). As distinct from the Bocare or swamp immortelle, the anauca is grown in the hilly areas of Trinidad. It has a very similar habit but does not make such a large tree. Fairly easy to establish from large cuttings.

Gliricidia maculata. *Gliricidia* is a well-known cocoa shade having the advantage of being easily established from long cuttings which grow rapidly. It possesses the disadvantage of flowering heavily during the dry season and being leafless for 4 or 5 weeks. This can be controlled by pruning before the end of the rains, the new young growth that develops not flowering to any marked extent. Its main value is as a temporary shade until larger trees can take over.

Inga laurina (Pois doux). In several cacao growing countries, viz. Costa Rica, various Ingas have been used. In the past in some of the West Indian islands liable to hurricane its smaller habit of growth has given it an advantage over the tall *Immortelle*. Nowell (1920), however, says that it tends to promote the spread of *Rosellinia* root disease and warns against its use.

Leucaena glauca. This tree is used very largely in the East where it provides a light diffuse shade. In Trinidad, however, it does not grow well and flowers during the dry season when very young. Shows little promise.

Parkia roxburghii. This tree does not establish very easily but makes rapid early growth with a fairly straight trunk. Crown is fairly compact but not too dense and this tree shows some promise. The development of buttress roots may, however, prove a disadvantage.

Pentaclethra macroloba (Bois mulatre). A medium sized native forest tree rather slow growing. Branches readily to give a rather close canopy and Marshall (1939) says it coppices easily at an advanced age. It is surface rooting and old trees may become hollow at the base.

Samanea saman (Samaan, rain tree). Makes rapid rather straggling early growth with rather sparse foliage. Can become a very large tree with great girth and spread. It has been used as cacao shade in Venezuela and Ecuador but as mature shade it tends to be too heavy and the long almost horizontal branches support numerous epiphytes.

Sesbania grandiflora. A rapidly growing soft wooded tree which has gone down badly to a root disease. It has a light feathery canopy.

Obviously many more years must elapse before any definitive conclusions may be drawn. At present *Parkia roxburghii*, *Pentaclethra macroloba* and *Enterolobium cyclocarpum* seem to be providing conditions under which the young cacao is doing well. Of the young introductions, *Schizolobium amazonicum* is making good growth and shows most promise.

The most satisfactory answer to the shade tree problem is perhaps the development of agricultural techniques and in particular the use of fertilisers to the point where the crop can be grown unshaded with windbreaks surrounding the fields. Under conditions of heavy soils with impeded drainage the problem may prove more intractable, for the absorption of fertilisers is impaired by poor root development.

There is some evidence that the life of a cacao tree without shade may be somewhat shorter than that of a shaded tree. However, progressive management should look to replanting cacao fields at 30-40 years. Only by so doing will best use be made of improved planting material being developed by selection and breeding. The absence of shade trees will obviously make such a replanting programme far easier to accomplish, the felling of large non-economic trees and their replanting being an

appreciable charge to a rehabilitation programme. Finally there is considerable evidence that the highest yield of cocoa is secured under conditions where the crop is

grown without permanent shade but with a high level of nutrition.

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Appendix

(All the 1952 plantings were made from locally available seed, the later plantings were introduced as indicated.)

	Native country	Year of planting	Average height (ft.)	Average spread (ft.)	Introduced from	Year of planting	Average height (ft.)
Adenanthera pavonina	South east Asia	1952	10-12	6-8			
Albizzia lebbek	N. Africa to Australia	"	20-25	15-18			
Azadirachta sp.	Indomalaya	"	7-8	3-4			
Caesalpinia coriaria	S. America	"	16-20	8-10			
Cassia multijuga	Trop. America	"	15-20	12-15			
Cassia reticulata	Trop. America	"	30-35	20-25			
Enterolobium cyclocarpum	S. America	"	40-45	20-25			
Erythrina glauca	Venezuela	"	12-15	10-12			
Erythrina poeppigiana	Peru	"	18-20	15-18			
Gliricidia maculata	S. America	"	20-25	6-8			
Inga laurina	W. Indies	"	20-25	15-18			
Leucaena glauca	Tropics—widespread	"	15-20	10-12			
Parkia roxburghii	Asia	"	40-50	16-20			
Pentaclethra macroloba	W. Indies	"	16-18	14-16			
Samanea saman	Central America	"	20-25	18-20			
Sesbania grandiflora	Trop. America	"	16-20	10-12			
Erythrina berteriana	Mexico	1953	10-12				
Erythrina velutina	Brazil	"	10-12				
Erythrina indica	Malaya	1954	5-6				
Ficus natalensis	Kenya	"	6-8				
Parkia javanica	Malaya	"	10-12				
Peltophorum dasyrachis	Malaya	"	7-8				
Albizzia grandibracteata	E. Africa	1955	8-10				
Erythrina lithosperma	Samoa	"	8-10				
Indigofera teysmanii	Dominica	"	10-12				
Acacia polyphylla	Brazil	1956	4-5				
Albizzia procera	Assam	"	6-8				
Albizzia stipulata	Assam	"	6-8				
Schizolobium amazonicum	Brazil	"	8-10				
Sterculia bombacea	New Guinea	"	4-5				
Stryphnodendron guianensis	Brazil	"	6-8				

Further Observations on the Susceptibility of Imperial College Selections to Witches' Broom Disease

by
Paul Holliday*

Introduction

PREVIOUS work at the College on the susceptibility of its clones to witches' broom disease was summarised by Holliday (1954) together with pod infection records for 30 clones in CRB 1-6. Further results are presented here from the CRB clonal trials at River Estate. These continue, after CRB 6, in CRB 11-16.

Cushion and vegetative infection

Records are given over two seasons for CRB 6 and CRB 11-14. Following Baker and Crowdy (1943) the degree of infection was assessed by counting the number of cushion and vegetative brooms. A more resistant clone is therefore one which forms fewer brooms, not brooms smaller in size. Two plots, normally of 16 trees each, were picked at random from each clone in each CRB and every tree cleared of brooms in October of each season. The following April the same trees were again searched and both types of brooms counted. In Trinidad practically all the brooms formed in a year occur from November to March. In some plots, notably those in CRB 14, the full quota of 16 trees per plot was not recorded. Either because the trees were supplies, i.e. very small, or because they were

missing. In 12 of the 25 clones (ICS 27, 31, 46, 49, 62, 67, 68, 73, 74, 80, 87 and RT 18) between 24 and 31 trees were recorded; in the remainder the full number of 32. No correction was made for size of tree. Trees in CRB6 were of mature size. Those in the other CRB's were younger and are rather variable for age. In the first season (1953-54) trees in CRB 11, 12 and 13 were mostly 5-7 years old whilst those in CRB 14 were two years younger.

Pod infection

Records are given for CRB 11-13 over three seasons and for CRB 14 over two seasons. No results are available yet for the very young plantings CRB 15 and 16. Since all the trees examined are relatively young and are therefore liable to set much of their crop in the dry season when infection is negligible (Holliday and Baker 1953), all analyses have been done on the crop reaped from October to May. This crop is set at a time when conditions are favourable for infection. All percentages of diseased pods, on which the analyses have been made, were first transformed by the angular transformation (Snedecor 1946).

Experiment CRB 6 (ICS 1, 25, 31, 32, 36, 67)

TABLE I

Cushion and vegetative infection as the mean number of brooms per tree of each clone

Season (Oct.-Apr.)	Brooms	ICS 1	ICS 25	ICS 31	ICS 32	ICS 36	ICS 67	SE clone difference
1953-54	Vegetative	2.0	6.8	1.5	5.7	31.3	25.3	} ± 3.02
	Cushion	0.1	0.2	0.0	0.3	2.3	1.8	
	Total	2.1	7.0	1.5	6.0	33.6	27.1	
1954-55	Vegetative	1.4	5.3	1.2	3.6	41.5	35.0	} ± 7.79
	Cushion	0.0	0.0	0.0	0.2	0.8	0.5	
	Total	1.4	5.3	1.2	3.8	42.3	35.5	

The clones divide themselves into three groups, the same for each season. The resistant ICS 1 and 31, the susceptible ICS 25 and 32, and the extremely susceptible ICS 36 and 67. ICS 36 is significantly the worst. None

of the clones are self-sterile so that cushion broom formation is not high and the differences do not approach significance. Pod infection for CRB 6 has been reported previously (Holliday *loc. cit.*).

* Now at the Commonwealth Mycological Institute, Kew.

Experiment CRB 11 (ICS 1, 27, 39, 43, 65 and SCA 6)

TABLE II

Pod infection as means per plot of 16 trees of each clone

Season (Oct.-May)	ICS 1	ICS 27	ICS 39	ICS 43	ICS 65	SCA 6	SE clone difference	Means
1952-53	10.23 (3.4)	8.19 (3.2)	10.48 (3.2)	12.96 (5.5)	10.27 (5.1)	1.11 (0.1)	±1.66 —	— (3.1)
1953-54	11.02 (3.8)	5.81 (3.7)	12.74 (5.6)	16.21 (7.8)	12.77 (6.8)	1.79 (0.1)	±1.79 —	— (3.5)
1954-55	18.60 (10.4)	23.36 (17.6)	20.41 (13.1)	25.82 (19.3)	27.38 (21.1)	4.43 (0.7)	±2.17 —	— (11.6)

Without brackets transformed percentages. Within brackets actual percentages.

Using ICS 1 as a standard none of the clones is very susceptible. ICS 43 is worse than ICS 1 in two seasons whilst ICS 27 is better. ICS 27, 43 and 65 are worse

than ICS 1 in the last season. The experiment confirms the extremely high resistance of SCA 6, an Amazon clone from Pound's collections.

TABLE III

Cushion and Vegetative infection as the mean number of brooms per tree of each clone

Season (Oct.-Apr.)	Brooms	ICS 1	ICS 27	ICS 39	ICS 43	ICS 65	SE clone difference
1953-54	Vegetative	1.8	1.1	3.1	9.1	1.1	} ±1.97
	Cushion	0.1	0.1	21.3	2.4	0.2	
	Total	1.9	1.2	24.4	11.5	1.3	
1954-55	Vegetative	3.8	5.9	10.8	20.1	7.1	} ±2.26
	Cushion	0.2	0.2	10.3	3.9	0.1	
	Total	4.0	6.1	21.1	24.0	7.2	

The trees of ICS 27 and 65 tend to be rather small and this should be considered when assessing the differences. SCA 6 was examined, but since no brooms were found, it was omitted from the analysis. At present this clone and SCA 12—found in CRB 12—can be considered im-

mune to vegetative and cushion infection. ICS 43 is easily the worst for vegetative infection whilst ICS 39 is also poor. There is little difference between the other three clones. ICS 39 and 43 are self-sterile and more susceptible to cushion infection, especially the former.

Experiment CRB 12 (ICS 1, 24, 49, 62, 84 and SCA 12)

TABLE IV

Pod infection as means per plot of 16 trees of each clone

Season (Oct.-May)	ICS 1	ICS 24	ICS 49	ICS 62	ICS 84	SCA 12	SE clone difference	Means
1952-53	9.28 (3.6)	18.57 (11.4)	6.20 (2.8)	—	10.13 (3.8)	0.34 (0.03)	±2.01 —	— (3.4)
1953-54	10.70 (3.2)	12.62 (6.2)	10.14 (4.4)	7.53 (6.6)	13.89 (6.0)	0.26 (0.05)	±2.56 —	— (3.1)
1954-55	16.26 (8.0)	29.57 (25.01)	15.25 (8.0)	19.50 (11.1)	20.76 (13.2)	2.41 (0.4)	±2.75 —	— (10.2)

Without brackets transformed percentages. Within brackets actual percentages.

ICS 24 is the worst clone with significantly more infection than ICS 1, 49 and 84 in two seasons. ICS 62 has made poor growth and the results must be treated with

caution. ICS 84 is rather worse than ICS 1 and 49. SCA 12 carries as little infection as SCA 6; both are practically immune to pod infection.

TABLE V
Cushion and Vegetative infection as the mean number of
brooms per tree of each clone

Season (Oct.-Apr.)	Brooms	ICS 1	ICS 24	ICS 49	ICS 62	ICS 84	SE clone difference
1953-54	Vegetative	2.2	0.6	0.8	0.4	1.8	} ± 0.27
	Cushion	0.1	0.1	0.3	0.0	0.4	
	Total	2.3	0.7	1.1	0.4	2.2	
1954-55	Vegetative	2.5	0.8	3.0	1.3	3.1	} ± 0.70
	Cushion	0.1	0.0	1.2	0.8	0.5	
	Total	2.6	0.8	4.2	2.1	3.6	

No brooms were formed on SCA 12 and it has been omitted from the analysis. There are no very susceptible ICS clones and ICS 24 seems to be one of the few better than ICS 1. Although both ICS 49 and 84 are self-sterile

they do not produce large numbers of cushion brooms. The low incidence of the disease in CRB 12 reflects the absence of any very susceptible clones.

Experiment CRB 13 (ICS 1, 23, 39, 40, 80, RT 18)

TABLE VI
Pod infection as means per plot of 16 trees of each clone

Season (Oct.-May)	ICS 1	ICS 23	ICS 39	ICS 40	ICS 80	RT 18	SE clone difference	Means
1952-53	11.42 (4.6)	9.59 (7.4)	7.72 (5.6)	10.65 (4.3)	17.00 (8.6)	12.91 (5.8)	± 3.00 —	— (5.7)
1953-54	11.57 (5.4)	15.77 (8.3)	16.78 (9.4)	12.78 (5.5)	15.78 (8.3)	15.79 (9.1)	± 2.20 —	— (7.7)
1954-55	20.86 (13.5)	26.46 (19.1)	21.68 (15.3)	20.99 (13.3)	26.75 (20.6)	26.56 (19.8)	± 1.92 —	— (16.9)

Without brackets transformed percentages. Within brackets actual percentages.

ICS 1 is again one of the best clones whilst ICS 23 and 80 and the thrips resistant clone (RT 18) are rather sus-

ceptible. ICS 39 and 40 occupy an intermediate position.

TABLE VII
Cushion and Vegetative infection as the mean number of
brooms per tree of each clone

Season (Oct.-Apr.)	Brooms	ICS 1	ICS 23	ICS 40	ICS 80	RT 18	SE clone difference
1953-54	Vegetative	2.5	0.6	2.6	2.5	7.1	} ± 1.13
	Cushion	0.1	0.1	12.1	0.9	0.1	
	Total	2.6	0.7	14.7	3.4	7.2	
1954-55	Vegetative	3.4	2.4	8.3	3.2	14.0	} ± 2.08
	Cushion	0.4	0.1	27.2	1.3	0.1	
	Total	3.8	2.5	35.5	4.5	14.1	

ICS 39 has been omitted since it occurs in CRB 11. ICS 40 is a rather vigorous self-sterile clone, and is very susceptible, producing large numbers of cushion brooms and being also fairly susceptible to vegetative

infection. ICS 23 and 80 are somewhat resistant, but RT 18 is definitely poor with more fan brooms than the other four clones. In this CRB, ICS 23 has grown rather poorly.

Experiment CRB 14 (ICS 1, 46, 68, 73, 74 and 87)

TABLE VIII

Pod infection as means per plot of 16 trees of each clone

Season (Oct.-May)	ICS 1	ICS 46	ICS 68	ICS 73	ICS 74	ICS 87	SE clone difference	Means
1953-54*	11.1 (3.8)	7.53 (2.8)	8.90 (3.5)	11.38 (4.3)	13.59 (5.5)	4.98 (2.9)	±3.56 —	— (3.6)
1954-55	12.31 (4.8)	13.77 (5.7)	17.06 (9.3)	15.31 (8.5)	26.20 (20.1)	19.99 (12.0)	±3.08 —	— (9.2)

* Cuttings only, sub-plots of 8 trees. Without brackets transformed percentages. Within brackets actual percentages.

The trees in this set are too young for more than two seasons records. ICS 74 seems an extremely poor clone with an infection rate more than four times that of ICS 1

in the last season when incidence of the disease was greater. ICS 87 is rather susceptible; ICS 1 and 46 are the best.

TABLE IX

Cushion and Vegetative infection as the mean number of brooms per tree of each clone

Season (Oct.-Apr.)	Brooms	ICS 1	ICS 46	ICS 68	ICS 73	ICS 74	ICS 87	SE clone difference
1953-54	Vegetative	1.4	0.8	1.7	0.6	1.2	2.2	} ±0.39 ±0.21
	Cushion	0.1	0.6	0.1	0.0	0.0	0.4	
	Total	1.5	1.4	1.8	0.6	1.2	2.6	
1954-55	Vegetative	4.3	3.7	7.4	3.0	3.4	11.1	} ±0.87 ±0.57
	Cushion	0.0	2.4	0.0	0.1	0.2	0.4	
	Total	4.3	6.1	7.4	3.1	3.6	11.5	

Infection seems low, too low to do more than indicate clonal behaviour. ICS 87 is the worst, being rather susceptible to vegetative infection. ICS 46 and 68 are

intermediate and definitely worse in one season than ICS 1, for vegetative infection. ICS 46, a self-sterile clone, produced the most cushion brooms.

Discussion

The results confirm earlier observations made on the older clonal trials at River Estate. These are: (1) that wide, significant variations exist in the behaviour of different clones; (2) that in general there is a positive correlation between pod and vegetative infection; (3) that self-sterile clones tend to form more cushion brooms than self-compatible ones; (4) and finally that, as far as pod infection is concerned, cuttings and buddings behave similarly.

Before an attempt is made to classify the clones discussed above it should be pointed out that infection in field 6, where CRB 11-14 occur, is clearly less than it was amongst the older CRB 1-6 in field 7. Therefore the differences between clones in the former field are not always so marked as they were in the latter. The mean percentage pod infection for ICS 1 in CRB 1-4 and 6 over three seasons (a total of 480 trees) was 11.9%. In CRB 11-14 over three seasons (a total of 384 trees) it was 5.9%. Likewise, a drop in vegetative infection has occurred in field 6 when compared to field 7. The reason for this is clear. The earlier CRB's were planted in field 7 when most of the estate was still in old seedling cacao heavily infected with witches' broom disease. Spore showers

continually infected these trials (Baker *et al.* 1941). When, towards the end of 1949, all the old seedling stands had been removed from River Estate, infection still tended to remain higher than it ever has been in field 6. This observation strengthens the view, generally held, that it is extremely difficult—without drastic precautions—to reduce the disease to insignificance once it has become well established. If, however, clones are planted under conditions where infection from outside is slight, as in field 6, they may be brought to maturity showing little infection, by using the standard method of control recommended for Trinidad. This is perhaps stating the obvious, but it is too little realised that young cacao must be given as good a start with respect to disease control as with any other factor such as soil site or fertiliser treatment.

In Table X an attempt is made at assessing susceptibility to pod, cushion and vegetative infection from the above five experiments. Overall susceptibility is given in Table XI. SCA 6 and 12 being in a class by themselves are omitted and in Table X pod infection ratings for CRB 6 have been left out because they have been previously given (Holliday *loc. cit.*). ICS 1 present in all CRB's, and already classed as fairly resistant to broom production and resistant to pod infection, has been used as a standard.

TABLE X
CRB 6 and 11-14 Susceptibility of clones to pod, cushion
and vegetative infection

Infection type	Resistant	Fairly resistant	Susceptible	Very susceptible
Vegetative	ICS 23, 24, 73	ICS 1, 27, 31, 40, 46, 49, 62, 74, 80	ICS 25, 32, 39, 65, 68, 84, RT 18	ICS 36, 43, 67, 87
Cushion	ICS 24, 31, 73	ICS 1, 23, 25, 27, 32, 62, 65, 68, 74, RT 18	ICS 36, 43, 46, 49, 49, 67, 80, 84, 87	ICS 39, 40
Vegetative and Cushion*	ICS 24, 73	ICS 1, 23, 27, 31, 62, 74	ICS 25, 32, 46, 49, 65, 68, 80, 84, RT 18	ICS 36, 39, 40, 43, 67, 87
Pod	ICS 1, 39, 40, 46, 49	ICS 27, 68, 73	ICS 23, 43, 62, 65, 80, 84, 87, RT 18	ICS 24, 74

* i.e. total broom production.

Only six clones do not show any correlation between broom production and pod infection. They are ICS 24, 39, 40, 46, 49 and 74, all of these, except ICS 24, are self-sterile with a tendency to produce many cushion brooms. ICS 74 is an exception in being very susceptible to pod infection. Although the self-sterile clones (ICS 39, 40, 43, 46, 49, 74, 80, 84 and 87) gave a mean number of

4.21 cushion brooms per tree per year compared with the figure of 0.03 for the self-compatible clones they are not all uniform for cushion infection. Only ICS 39 and 40 seem to belong to the group of vigorous self-sterile trees, typified by ICS 60, which are extremely susceptible to cushion infection but carry a low pod infection rate.

TABLE XI
CRB 6 and 11-14 overall susceptibility of clones

Resistant	Fairly resistant	Susceptible	Very susceptible
—	ICS 1, 23, 27, 31, 46, 49, 73	ICS 24, 25, 32, 62, 65, 68, 80, 84, RT 18	ICS 36, 39, 40, 43, 67, 74, 87

None of the clones shows the good overall resistance of ICS 91, 95 and 98 (Holliday *loc. cit.*), but six are as good as ICS 1. Further investigations would be desirable on ICS 23, 27, 62, 65 and 68 since these have made rather

poor growth. Of the original ICS selections, numbering a little over 100, a total of 46 have now been examined for susceptibility to the disease. Table XII summarises the behaviour of all these clones.

TABLE XII
Overall susceptibility of the ICS clones

Resistant	Fairly resistant	Susceptible	Very susceptible
ICS 6, 38, 45, 91, 95, 98, 101	ICS 1, 2, 23, 27, 31, 44, 46, 49, 55, 73, 85	ICS 5, 7, 8, 12, 22, 24, 25, 32, 54, 62, 65, 68, 70, 80, 84	ICS 3, 4, 9, 16, 36, 39, 40, 43, 53, 60, 67, 74, 87

Summary

Further examination of the ICS clones for susceptibility to witches' broom disease confirms earlier results that wide variations exist and that usually those clones most susceptible to pod infection will produce most brooms.

In CRB 6 and 11-14 the more resistant clones are

ICS 1, 23, 27, 31, 46, 49 and 73. The most susceptible are ICS 36, 39, 40, 43, 67, 74 and 87.

A total of 46 ICS clones have now been examined. Clearly the best is ICS 95.

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A Note on the Effect of Maleic Hydrazide Sprays on Cacao Seedlings and Cuttings

by

R. Nichols

FURTHER work has been carried out to extend the investigations of Murray and Nichols (1954) on the effect of maleic hydrazide on rooted cuttings and seedlings.

The results are essentially similar to those previously reported except that rooted cuttings may show the appearance of narrow, twisted leaves when sprayed with 0.1% maleic hydrazide. This observation had been reported on sprayed seedlings at similar or higher concentrations. Consistent loss of apical dominance of

seedlings was not found.

The similarity in behaviour of cuttings and seedlings suggests that there is no justification in postulating that a different physiological mechanism is operative with respect to maleic hydrazide in the two types of plant.

No positive correlation has been found between maleic hydrazide spray treatments and flushing behaviour and it is therefore not intended to use this compound in field trials.

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Nitrogen Metabolism in Fermenting Cacao

by
K. W. De Witt

DURING the fermentation of cacao the two major components of the bean affected are the polyphenols (Forsyth 1952, 1955) and the protein. It has been known for many years that nitrogen is lost from the cotyledons of the cacao bean during fermentation, and Birch (1940) showed that proteolysis takes place, with the formation of soluble nitrogenous substances, which can diffuse through the testa of the bean. In view of the probable relationship between these changes and the success, or otherwise, of the fermentation, it appeared desirable to examine them in greater detail.

Experimental

All cacao used in these experiments was taken from plots of ICS 1 clonal cacao growing at River Estate. Fermentations were carried out in the solar fermentary (De Witt 1953) in batches of 30 lbs. (wet weight) for eight days, mixing and turning on alternate days. Each fermentation was sampled immediately after each mixing, and analysis was begun within two hours of sampling.

Ten-bean subsamples were peeled, and the cotyledon tissue was macerated three times in a Waring blender with a total of 400 ml. of 70% ethanol, filtering the blend each time with suction. The filtrate was made up to 500 ml. with distilled water, and analysed immediately for total N, free and peptide-bound α -amino N. The residue was dried, de-fatted and analysed for total N, and for protein-bound α -amino N.

The following analytical methods were used:

Total N. Kjeldahl digestions were carried out using hydrogen peroxide as catalyst (Miller and Miller 1948) followed by distillation in a Markham (1942) still into boric acid, and titration with HCl (Ma and Zuazaga 1942). **α -amino N.** Amino acid was estimated colorimetrically with ninhydrin by the method of Wiggins and Williams (1954). The copper method (Pope and Stevens 1939) proved unsuitable owing to interference by the polyphenolic material present in the solution (De Witt 1955).

Peptide-bound α -amino N. Solutions were hydrolysed by refluxing in the presence of an equal volume of HCl, the HCl removed by repeated evaporation under reduced pressure, the residue dissolved in water, and amino acid estimated as above. In all cases, "six-hour" and "eighteen-hour" peptide was estimated, i.e. each sample was hydrolysed separately for 6 and 18 hours, and the additional amino acid liberated by the longer hydrolysis calculated by difference.

Protein-bound α -amino N. The ethanol insoluble material was hydrolysed in a sealed tube with 6N HCl at 100°C. for 18 hours. The HCl was removed by repeated

evaporation under reduced pressure and amino acid determined as above.

The amino acids of cacao protein were analysed by chromatography on Dowex 50 columns by the method of Moore and Stein (1951), using the method of Yemm and Cocking (1955) for analysis of the eluate fractions.

Paper chromatography was carried out on Whatman No. 1 paper using butanol : formic acid : water (60 : 5 : 35) as developing solvent (Wiggins and Williams 1952).

Results

The analytical results are quoted in terms of the mean content per bean in each case. Owing to changes in the moisture content and dry weight during fermentation, this system gives a more realistic picture of nitrogen metabolism than percentage figures. The degree of variation to be expected between measurements can be gauged from the standard deviations for small groups of different samples of fresh beans from one clone shown in Table I.

TABLE I

Means and Standard deviations between different samples of beans

	No. of samples	Mean	S.D.	S.D. % mean
Total N	5	27.218	2.164	7.95
Ethanol-insoluble N	5	19.618	1.673	8.53
Free α -NH ₂ N ...	6	0.695	0.058	8.34

The standard deviations for replicate measurements on the same sample were of the order of one-tenth of those between samples, the sampling error being the main contributor to the variance between measurements.

The experiments were carried out during the 1954-55 crop season (November-May) and covered a range of fermentation conditions. The products of the fermentation correspondingly varied from well fermented to under fermented as judged by the cut test (De Witt 1953). Typical results for two extreme types are given in Tables II and III, to show the difference between "good" and "poor" fermentation. The former was carried out in November, in the wet season, and produced a dark, well fermented cacao. The other took place in early January during a spell of dry weather, and the customary precautions necessary to secure satisfactory fermentation under dry conditions, such as prolonging the fermentation or moistening the cacao, were omitted. The product was distinctly underfermented.

TABLE II

Nitrogen distribution during wet season fermentation.
Analytical results in mg. per bean

Time of fermentation (hrs.)	0	41	89	137	185
Fresh cotyledon weight ...	2,202	2,308	2,311	2,199	2,188
Dry cotyledon weight ...	1,362	1,406	1,292	1,245	1,186
Soluble in 70% ethanol ...	305	311	195	299	236
Insoluble in 70% ethanol, fat-free ...	539	553	522	488	455
Total nitrogen ...	27.78	31.20	25.06	23.15	21.59
Ethanol-insoluble N ...	20.50	20.80	12.72	10.60	10.06
Free α -amino N ...	0.73	1.03	2.27	2.28	2.40
"6-hr. peptide" α -amino N ...	0.21	0.23	2.64	2.14	1.17
"18-hr. peptide" α -amino N ...	0	0	0	0.54	1.06
Protein α -amino N ...	11.96	9.97	6.93	2.00	1.34

Fermentation November 2nd-10th, 1954, ICS 1 cacao. Rainfall during the fermentation period, 2.77 inches. *Cut test* (100 beans): Well fermented 65; moderately fermented 25; under fermented 10 beans.

TABLE III

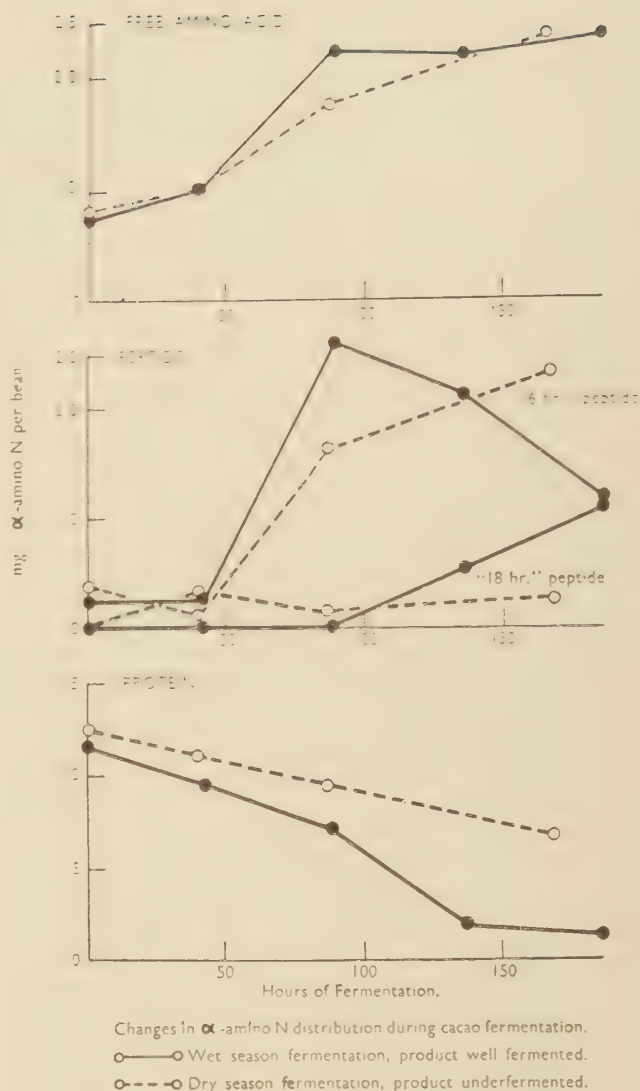
Nitrogen distribution during early dry season fermentation.
Analytical results in mg. per bean.

Time of fermentation (hrs.)	0	40	88	167
Fresh cotyledon weight ...	2,248	2,270	2,306	2,247
Dry cotyledon weight ...	1,412	1,388	1,340	1,302
Soluble in 70% ethanol ...	294	293	230	272
Insoluble in 70% ethanol, fat-free ...	601	528	574	522
Total nitrogen ...	30.21	31.10	29.75	28.35
Ethanol insoluble N ...	21.35	19.93	17.98	15.04
Free α -amino N ...	0.81	1.03	1.77	2.42
"6-hr. peptide" α -amino N ...	0.35	0.13	1.65	2.34
"18-hr. peptide" α -amino N ...	0	0.31	0.16	0.29
Protein α -amino N ...	12.48	11.05	9.53	6.40

Fermentation from January 3rd-11th, 1955, ICS 1 cacao. Rainfall during the fermentation period 0.61 inch. *Cut test* (100 beans): Well fermented 45; moderately fermented 20; under fermented 35 beans.

A comparison of the changes in amino acid distribution is shown in Fig. 1. In the first good fermentation, protein amino acid disappeared steadily throughout, while the soluble forms increased rapidly for the first three days; thereafter the free amino acid remained constant, while the soluble peptide material decreased in total amount. During this stage, an increase in the more complex soluble peptide fraction occurred. In the second, poor, fermentation, a similar series of changes occurred, but at a much slower rate. For example, the end product still contained over half the initial amount of protein-bound amino acid, whereas very little was left in the well fermented cacao. The maximal value for soluble amino acid and peptide was reached at the end, instead of after three days' fermentation.

An increase in the total nitrogen of the cotyledons was observed in both fermentations on the second day. A similar effect was observed by Birch (1940). It is apparently due to the absorption of nitrogen from the testa during the initial period of fermentation, since analysis of the testa and pulp showed a slight decrease in N content during this period.



A number of claims have been made that the changes in the cacao beans produced by fermentation can be simulated by heating fresh cacao beans (Wadsworth and Howat 1954, cf. Knapp 1937, p. 121). Experiments were made to determine whether heat-treatment could induce the proteolysis with formation of free amino acids described above. The results are shown in Table IV.

TABLE IV

Changes in free α -amino N (mg./bean) in heat-treated cacao beans

Treatment time (hrs.)	0	24	48	72	96
Temp.—40° ...	0.62	0.88	1.05	1.17	1.26
45° ...	0.70	1.08	1.12	1.21	1.21
50° ...	0.64	0.89	0.82	1.08	—

It is evident that while heat-treatment does cause a slight increase in free amino acid, the change is much slower than in the case of fermentation.

The composition of the cacao protein hydrolysate of fresh ICS 1 beans is shown in Table V.

TABLE V
Amino acid composition of cacao protein hydrolysate

			mgN/bean	μequiv./bean				mgN/bean	μequiv./bean
Aspartic acid	...	...	1.63	116.4	Cystine	...	...	0.07	5.3
Glutamic acid	...	...	2.28	162.5	Methionine	...	...	0.05	3.4
Glycine	...	...	1.43	102.4	Proline	...	...	0.71	50.7
Alanine	...	...	0.84	60.1	Tryptophan	...	...	0.18	6.3
Valine	...	...	0.43	30.8	Histidine...	...	...	0.24	8.7
Leucine	...	...	0.67	47.8	Lysine	...	...	1.36	48.7
Isoleucine	...	...	0.25	17.5	Arginine	...	...	2.82	50.4
Serine	...	...	0.93	66.3	Ammonia	...	...	4.36	311.5
Threonine	...	...	0.72	51.3					
Phenylalanine	...	...	0.68	48.4					
Tyrosine...	...	...	0.63	44.7					
					TOTAL	...	...	20.28 mgN/bean	

Almost all the ethanol-insoluble nitrogen is thus accounted for in the fresh bean.

During the fermentation, the ninhydrin-reacting substances in the ethanol-soluble fraction increased both in quantity and variety. Initially, only aspartic and glutamic acids and their amides, alanine, proline, α -amino-butyric acid, valine and leucine were detectable. As the fermentation proceeded, other substances were formed so that ultimately the amino acids appeared on the chromatogram as darker spots against a continuous background of colour. One noticeable feature was the appearance of spots of higher R_F value than leucine very shortly after fermentation begins.

Discussion

It has previously been pointed out (De Witt 1952) that a normal cacao fermentation can be divided into two clearly marked stages. The first stage is anaerobic (Forsyth and Rombouts 1951) and takes approximately three days, during which the temperature is rising to its maximum value of 48°-50°C., the bean is killed by heat, absorbs water and swells. The pigment cells of the cotyledon break down, and the purple colour of the anthocyanin is bleached (Forsyth 1952). In the second stage terminating with drying, oxygen penetrates the fermenting mass, and the polyphenols liberated from the pigment cells are oxidised by the powerful polyphenol

oxidase of the cacao bean (Moore, Greninger and Rusoff 1952) so that both the pulp and the cotyledons begin to turn brown. This second stage terminates when drying reduces the moisture content of the bean below the level at which oxidation can occur. The planter usually controls the final colour of his cacao by adjusting the rate of drying, so that the oxidation is halted at the desired stage. It is generally accepted by planters that cacao needs less fermentation during wet weather, as under dry conditions evaporation from the fermenting box reduces the moisture content of the pulp and the cotyledon, which in turn slows down the microbiological and biochemical processes of fermentation.

The results described above show that during the whole of the fermentation protein is being destroyed, the rate of destruction depending upon the fermentation conditions, so that very little true protein remains in well fermented cacao. The decrease in the ratio of α -amino N to total N in the ethanol-insoluble fraction of the bean from 0.58 to 0.13 (cf. Table II) during the fermentation indicates that protein is removed in at least two ways—by proteolysis, with the formation of amino acids and peptides, and also by transformation into an insoluble non-protein form, which is hydrolysed by acid to soluble, but ninhydrin-negative material. A combination of oxidation and tanning in the presence of polyphenol and polyphenol oxidase suggests itself as a mechanism for the latter process.

TABLE VI
Nitrogen balance in fresh, under-fermented and fermented cacao from Tables II and III

		N (mg/bean)		
		Unfermented	Under-fermented	Fermented
Ethanol-insoluble	Protein amino acid N	15.91	8.51	1.78
	NH ₃ N	4.36	2.33	0.09
	Not accounted for (a)	0.23	4.20	7.79
Ethanol soluble	Free-amino N ...	0.73	2.42	2.40
	Peptide-amino N ...	0.21	2.63	2.23
	Purine N (b)... ..	5.21	4.30	3.92
	Not accounted for (c)	1.14	3.96	2.98
TOTAL		27.79	28.35	21.59

Notes : (a) by difference

(b) calculated from Humphries (1939), Haworth (1951)

(c) by difference ; including amide-N, approximately 0.50 mg/bean

In the fermented cacao, 44% of the total nitrogen is in digestible forms (amino acid, peptide, protein, etc.) (Table VI). Feeding and enzyme digestion experiments at various times (for references see Mitchell, Beadles and Keith 1926) have shown that the percentage of digestible cacao nitrogen can vary between 40% and 70%. The experimental results given here offer an explanation for these differences, in that the amount of digestible N varies inversely with the degree of fermentation; a low-grade, poorly fermented cacao will contain more digestible N as in the under-fermented cacao, which contains 70% of its total N in digestible forms. The amount of protein-bound α -amino N remaining in the cotyledons could, in fact, be used as a chemical test for the completeness of fermentation. The relationship between the degree of fermentation and the residual protein suggests a correlation between the presence of protein and the development of raw, nutty flavour and aroma on roasting under-fermented cacao—a similar type of aroma to that developed when a vegetable protein is roasted with glucose. It is well known that high grade cacao varieties contain less nitrogen than low quality cacaos (Hardy and Rodrigues 1951). A further part in the development of off-flavours in cacao is played by the products of proteolysis. In over-fermented cacao, fishy or ammoniacal flavours appear in the cotyledons, due to the formation of nitrogenous bases in the pulp, which diffuse into the cotyledons on prolonged fermentation. A source of these substances is provided by the amino acid and peptides diffusing from the cotyledons.

Finally, it would seem that more than the effect of high temperature on the cacao beans is involved in fermentation despite the fact that it is possible, by heat-treatment, to simulate the texture and colour of fermented cacao. It has been suggested (De Witt 1951; Wadsworth and

Howat 1954) that during the first part of fermentation, the temperature should not rise so rapidly that the biochemical changes due to incipient germination are ended prematurely. However, even at 40°, where the bean survives as long as 40-50 hours, heat-treatment does not cause as rapid a change in free amino acid concentration as in fermentation. The only alternative explanation of the difference between heat-treatment and fermentation is the presence of substances formed by microbial fermentation of the pulp, namely alcohol and acetic acid, both of which occur in high concentration during the first stage of the fermentation.

Summary

(1) The nitrogenous components of cacao have been analysed at various stages of fermentation carried out at different times during the harvesting season.

(2) Protein is removed during the fermentation, by hydrolysis to amino acids and peptides, and by conversion to an insoluble fraction which does not yield amino acid on hydrolysis. In well fermented cacao, very little protein remains at the end of fermentation; the quantity of protein-bound amino acid is suggested as a measurement of the degree of fermentation. Liberation of amino acids in cacao heated to fermentation temperatures without inoculation with micro-organisms occurs much more slowly than in fermentation.

(3) The amino acid composition of cacao protein has been determined both qualitatively and quantitatively.

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The Application of Research to the Cocoa Industry

by

A. L. Jolly, Lecturer in Economics, I.C.T.A.

It may appear to be not very appropriate in a scientific bulletin on cocoa research to include the musings of an economist on some of the more general problems of the industry. But research must always be tailored to the actual resources available to an industry; not only financial resources which may limit the application of some profitable but nevertheless costly technique but also the resources of labour and management. A labour intensive technique may be inapplicable in an area where population is sparse; a new technique requiring—as most do—more refined management may be entirely wasted if managers are too few, too inefficient or too conservative in the industry concerned. The relationship between resources available and research that is desirable is particularly important with cocoa because this industry is rather exceptional among the tropical staples. These peculiarities do not appear to be generally appreciated and will bear repeating.

Cocoa was never a common forest tree and even from the remotest times the produce appears to have been obtained from deliberate plantings. The invention of the manufacture of chocolate and so the amplification of the market for cocoa beans occurred at a time when the real earnings of labour in the industrially developing countries of Europe were increasing steadily. The increase was fairly continuous from about 1870 to 1920 and the market for this working man's luxury increased steadily during that period. Since increased production could only be obtained from man-made plantings, which were slow to come into full bearing, supply never overtook demand during those 50 years and prices remained remarkably stable and remunerative for that long period. By contrast the plantation rubber industry of the Far East, similar originally to cocoa in many respects, was faced with what appeared to be completely unprofitable prices within 10 years of its original establishment.

Such a long uninterrupted period of prosperity in the cocoa industry led to a feverish search for new lands to plant in the crop all over the tropical world. Capital was plentiful because investment in established cocoa plantations proved year after year to be both safe and remunerative. The evidence of this world-wide search was that by 1910 the world supply of cocoa beans was obtained from many countries scattered over the length and breadth of the tropics, a very different situation from tea, coffee and rubber. Up to about 1910 the search for new cocoa lands completely overshadowed the research into more efficient methods of production. Because traditional methods consistently paid good returns, there was absolutely no incentive to change them; a few innovations, such as the use of budded trees and the application of organic manure, were fitfully tried but none became established practice of

the industry. Indeed the techniques of cultivation differed little from those observed by Cortes in Mexico 400 years previously.

When during the 1920's and '30's the massive increase in West African production resulted in the world supply finally overtaking the demand, the old producing areas were incapable of meeting the challenge. Not only had they failed to modernise their method of cultivation but their plantations were old and not as productive as in their youth. The planters in these areas were suddenly faced with an entirely new problem, that of improving field efficiency; it is no wonder that with the sudden fall in prices, the ignorance of anything but traditional planting techniques and the long-term nature of the crop most of them were unsuccessful in solving these difficulties. Furthermore, most of the old plantations deteriorated rapidly with the first efforts to economise on cultivation costs; many of those not ideally favoured by natural conditions failed entirely.

There is no reason to think that the West African cocoa farmer is fundamentally much different from his Western Hemisphere predecessor. The tremendous increase in African production from 1910 to 1935 was achieved entirely by increasing the area under the crop and not by increasing the production per acre. The techniques of the West African farmer have changed very little during the 45 years that he has been in production. He appears, if judged by his reaction to swollen shoot disease, to be even less resourceful with his cultivation than the plantation owners of older areas. Even if swollen shoot can be effectively controlled it is by no means certain that the West African farmer will be able to combat field senescence any more effectively than the planter elsewhere.

This historical sequence of 50 years profitable prices followed by 30 years unprofitable ones has proved to be a terrible handicap to the technical development of the producing side of the cocoa industry. Cocoa in the past has been veritably any fool's game; for the long period when the market was under-supplied anybody with enough suitable land could make a good living by relatively primitive agricultural methods; when the market became over-supplied no more efficient methods were to hand to make production profitable for the most skilful planter although unprofitable for the unskilled one. The period of high prices smothered technical progress; the period of low prices appeared so suddenly as to destroy the possibility of technical progress reducing its effect. The greatest handicap that history has placed on this industry is that it is generally not considered as a rewarding one for scientific management; indeed many of the keenest and most ingenious planters were driven out of the industry by the

depression. It has still not been proved nor become widely accepted that a skilful manager can make a much better return than an ignorant one and so the industry suffers generally from under-management. Evidence of under-management is shown by the fact that technical innovations are only slowly and patchily tested and are not rapidly adopted; there is no energetic drive for the new capital that is so urgently needed to improve plantations; there is little evidence of efforts to reorganise labour on up-to-date lines, etc.

There is a strictly limited area in the world in which conditions are suitable for growing cocoa because a combination of characteristics are required. A suitable area must possess the required features of rainfall and climate and if not yet planted in the crop must consist of fertile soils or be covered with rain forest; the population of the area must be dense enough to supply the required labour whether on peasant or plantation cultivations and must be sophisticated enough to be attracted by the rewards of the additional production obtained; the social and political organisation of the area must encourage individual effort by safeguarding private rewards and must be stable enough to make the required long-term investments appear attractive. With all these requirements it is no wonder that no large new areas in the tropics suggest themselves for planting and indeed many authorities are of the opinion that most of the areas where all these requirements exist have already been planted in the crop.

If large new areas that are suitable for cocoa do not at present exist and if management on established areas remains unprogressive, the cocoa planter and his industry will continue to remain a victim of every change in weather, of every new pest and disease and of every shift in the market. In such a vulnerable condition he is likely to fight a losing battle. Combinations of diverse circumstances will from time to time reduce production and result in a temporary jump in prices. The consumer, as he has done in recent years, is likely to react quickly to high prices by reducing his consumption on this rather non-essential, and although production may subsequently increase because the producer can start working his less productive fields consumption is not likely to re-expand so rapidly as it contracted. In the modern world there are many other possible avenues for expenditure by both young and old than on chocolate bars; as the efficiency in the production of other competitive products increases and they represent progressively to the consumer a better and better bargain for his money so will chocolate consumption fall out of favour. Cocoa and chocolate manufacture will be in danger of becoming waning industries.

Is it true, therefore, to conclude that research is outstripping the resources, and particularly the management resources, of the cocoa industry? There are some actual examples where it has. For instance the practicable preventative measure for swollen shoot which was evolved by the scientist would never have been applied by the farmer had not the Gold Coast Government made it compulsory and compensated individual farmers for the trees that were destroyed in the process. Again, the scientist has evolved superior planting material that is capable of yielding at double the rate of the material previously available and yet, in one country at least, a large proportion of these superior and expensive trees has been planted out into conditions in which they are unlikely ever to realise their potential high productivity.

Only a few thousand acres in the whole world have been planted with these trees under reasonable conditions, 20 years after their introduction. From such instances it might be concluded that the research is outstripping the capabilities of the industry to apply its findings.

The truth, however, is that there are two problems: the technical one of the scientist, and the management one of the planter. Each can be mutually obstructive; although scientific improvements cannot be applied without the required intensity of plantation management, improved management is unlikely to come about unless scientific refinements are discovered that will exercise such management. A primitive forest collecting industry remains in the hands of primitives; a more refined, more technical agricultural industry is the province of the college graduate because it demands and repays his special training.

However, although the two—technique and management—should go hand in hand they usually do not. The new techniques are developed in the laboratory and directly have no effect on the quality of field management. When the techniques are proved it is a slow process particularly in an industry on the lower rungs of development to improve management rapidly enough to take full advantage of the novel techniques. The natural process is for a few commercial pioneers to try the novelty; their success leads to imitation and a gradual widespread improvement of both management and technique.

Unfortunately with such a long-term crop as cocoa which is not very intensively managed, this natural process of evolution may take too long to bear fruit. Judged from the peculiarities of the crop and the industry, 50 years would not seem an inordinately long time to achieve by natural means an improvement in management large and broad enough for its effect to be felt in the market. During that period faith would have to be rebuilt in an industry still shaken by long years of depression in the '30's; the commercial vision of both peasant and planter would have to be lengthened from a year to year cultivation as he at present regards it to a generation to generation industry; these changes in the mental outlook of the planter would have to be complete enough to convince financial interest that vast new investment was necessary for replanting outmoded cultivations; when this new outlook has taken firm root and attracted new capital improved planting could commence and after perhaps 30 years a sufficient area would have been covered to represent an appreciable proportion of the world's production. At the present slow rate of progress along this difficult road, 50 years might seem a short period for the necessary revolution in cocoa cultivation. And yet 50 more years of the present low standards of technique and correspondingly rigid costs of production might effectively extinguish chocolate as a competitive article of consumption.

How can this over slow natural process of improving management be accelerated? The answer seems to be in forcing the development by example farms in existing cocoa areas to show planters and peasants in the most practical commercial terms that more progressive standards of management and higher capitalisation really do pay better than existing levels. It is not certain, however, that departments of agriculture are the most influential bodies to set up such example farms; government departments the world over have a reputation for lavish and uncommercial expenditure and example farms sponsored by government would always suffer from this stigma

however scrupulously they in fact adhered to the commercial principles. More influential examples could be sponsored by commercial houses who have an interest in the chocolate trade. At present they appear to be concentrating their efforts on developing plantations in new areas; these ventures will prove valuable only if such areas are ultimately capable of cocoa production on a large scale. If they prove to possess only small tracts with all the required conditions the application of the example will be correspondingly restricted.

The scope for commercial pioneering by the establishment of example farms is almost unlimited in existing producing areas. The scientist is developing a large number of improvements which in theory could double or treble the productivity of plantations in existing areas; likely new areas could not by any stretch of imagination make a contribution of this magnitude. There is, however, a very real danger in delay. The longer such pioneering

in existing areas is delayed the more confirmed will local opinion become that there is little opportunity for fresh investment or more intensive management in this industry; the longer the delay, the older and more decrepit will the plantations grow and the more true will this opinion become.

Potential pioneers of better cocoa planting therefore should not think exclusively or mainly in terms of new areas, the prospects of many of which seem very problematic; they should extend their efforts also to old areas where past development has proved that cocoa is a suitable crop. These areas are likely to go out of production entirely at some time in the future chiefly through lack of faith in an industry which so far has been based on unprogressive tradition. These old areas desperately need convincing examples that cocoa can be a progressive and profitable type of farming worthy of the best brains, high capitalisation and the most scientific management.

